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Aquaculture in the Americas

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Marine Fisheries Review

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Aquaculture in the Americas

A Symposium held in the framework of the Inter-American Scientific Meeting, "Science and Man in the Americas," 20 June to 4 July 1973, México 18, D.F., México.

Organized jointly by

American Association for the Advancement of Science (AAAS)

and

Consejo Nacional de Ciencia y Tecnología (CONACYT)

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INTRODUCTION

These papers, presented at the symposium "Aquaculture in the Americas," review current achievements in the field of aquaculture in the western hemisphere from technical, legal, and economic points of view. The symposium was held in conjunction with the Inter-American Scientific Meeting, Science and Man in the Americas, jointly sponsored by the American Association for the Advancement of Science (AAAS) and Consejo Nacional de Ciencia y Tecnología (CONACYT) 20 June to 4 July 1973 in Mexico City.

Panel discussions centered around the potential contribution of aquaculture to the economic and nutritional improvement of man's condition in the Americas. Emphasis was also given to the impact of aquaculture on man's environment and its potential for enhancing environmental quality.

Symposium organizers were Oswald A. Roels, Chairman and Cochairmen John Ryther and Henry J. Schafer. Oswald A. Roels is Professor, University Institute of Oceanography, City University of New York, N.Y., N.Y., and Chairman, Biological Oceanography, Lamont-Doherty Geological Observatory of Columbia University, Palisades, N.Y. John Ryther is Senior Scientist, Woods Hole Oceanographic Institution, Woods Hole, Mass. Henry J. Schafer is Director, Instituto Tecnologico y de Estudios Superiores de Monterrey, Escuela de Ciencias Maritimas y Tecnologia de Alimentos, Guaymas, Son.

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Gracilaria foliifera, .33 x

Seaweed Aquaculture

ARTHUR C. MATHIESON

Chondrus crispus, .50 x

INTRODUCTION

Seaweeds, or attached macroscopic marine algae, are a major source of potential food products in the sea. Today the seaweed industry is rapidly expanding because of the discovery of a variety of new seaweed products, especially those employing phycocolloids. In many cases the demand for seaweed products far exceeds their supply. Future growth of the seaweed industry will depend upon a stable source of high quality raw materials. Hence, many individuals and companies are interested in unialgal cultivation of economic seaweeds. Intelligent programs of conservation and harvesting are also necessary to maintain these valuable resources.

Gigartina sp., .30 x

Arthur C. Mathieson is with the Department of Botany and the Jackson Estuarine Laboratory, University of New Hampshire, Durham, N.H. *This paper is published with the approval of the Director of the New Hampshire Agricultural Experiment Station as Scientific Contribution Number 700. The paper was originally presented at the symposium Aquaculture in the Americas held at the Inter-American Scientific Meeting, "Science and Man in the Americas," jointly sponsored by the American Association for the Advancement of Science (AAAS) and Consejo Nacional de Ciencia y Tecnología (CONACYT), México 18, D.F., México, 20 June to 4 July 1973.*

Rhodymenia palmata, .30 x

In this paper the utilization and cultivation of seaweeds are presented in three aspects as follows:

(1) Uses of Seaweeds;

(2) Seaweed Aquaculture—an Overview;

(3) Seaweed Cultivation.

The first section summarizes the major usage of seaweeds throughout the world, and it gives a perspective for the need to cultivate seaweeds. It is abstracted from an earlier paper by the author (Mathieson, 1969). The second part discusses some of the major biological, technological, and sociological problems associated with seaweed cultivation. The Japanese have developed the most extensive systems of seaweed aquaculture; a detailed summarization of their accomplishments is given in the last section. In addition recent activities in other areas of the world are also outlined.

USES OF SEAWEEDS

Many species of seaweeds have been used as a direct source of food since ancient times, particularly in the East Asiatic-Australian region. The most diversified dietary use of seaweeds was developed by the ancient inhabitants of Hawaii, for 75 different seaweeds or "limu" were regularly used as food (Dawson, 1966). The Japanese and Chinese presently make extensive use of seaweeds as food (Bardach, Ryther, and McLarney, 1972).

The red alga *Porphyra*, or purple laver, is one of the major edible seaweeds in Japan. It has been harvested for food since ancient times, and at present it is the basis of a thriving nori[1] industry. *Porphyra* is presently cultivated and harvested on a commercial basis. The harvested material is dried, pressed into sheets, and subsequently packaged for market. The final product is used in soups, sauces, sandwiches, in the preparation of macaroni and various other commodities.

The larger brown algae (kelps) have also been used extensively as a source of food (kombu and wakame[2]) since before the Christian era. In Japan thin slices are used in soups and sauces and with vegetables. In addition they are mixed with meats, steeped in fresh water to make a drink, and, coated with sugar, eaten as a candy. Many of the smaller brown and green algae are also used in salads, as vegetables, garnishes for meats and fish, soups, sauces, and for making jellies (Okazaki, 1971).

The red algae, dulse (*Rhodymenia palmata*) and Irish moss (*Chondrus crispus*) are used as food in parts of western Europe, the Maritime Provinces of Canada, and New England. Dulse is eaten raw, cooked with soups, eaten with fish and butter, and used in a variety of other ways. Irish moss is dried and eaten out-of-hand like popcorn, or used in making blancmanges and soft jellies. The jelling qualities of Irish moss are due to the colloidal material (carrageenan) found within its cells. A soft jelly bread is also made from Irish moss. The Indians of the Pacific Northwest used *Porphyra* and the common sea lettuce (*Ulva*) as a source of food and salt (Scagel, 1961).

In general, seaweeds contain a high percentage of indigestible carbohydrates; in this sense they are comparable to roughage materials such as lettuce and celery. The greatest nutritional value of seaweeds lies in the various vitamins, minerals, and trace elements they contain. The amount of vitamin C in some brown and red algae is equal to or greater than that in a lemon. Most seaweeds are a good source of iodine, which aids in the normal functioning of the thyroid gland, and hence prevents goiter. The low frequency of goiter among Orientals is thought to be due to the large amount of seaweed in their diet.

Marine algae have long been used as fodders in coastal areas (particularly near the North Sea). The livestock in these areas are grazed directly on the seaweeds at low tide, and during the winter harvested seaweed is used to supplement their diet. Several types of meals and powders, which are primarily made from the brown alga, *Ascophyllum nodosum*, are now being used extensively for supplements to dried milk and other rations. They serve as valuable sources of vitamins and trace elements. Seaweed supplements are said to increase the wool production and growth of sheep, as well as to improve the color of egg yolks. Although several beneficial effects of seaweed meal have been recorded, some harmful side effects may result if the proportion of meal is too great.

Seaweeds such as *Ascophyllum nodosum* have long been used as green manures in maritime districts of Europe and North America. The fresh seaweeds were either dug into the ground or spread on the soil surface, and then allowed to decompose. The fertilizing constituents in fresh seaweeds are comparable to barnyard manure, except that they contain more potassium salts and less phosphorous (Scagel, 1961). They are considered to be more effective fertilizers than barnyard manures because they release their nitrogen and phosphorous compounds more slowly, they have more trace elements and growth substances, and there are no weed seeds or soil microorganisms.

Seaweeds were considered of medicinal value in the Orient as long ago as the year 3,000 B.C. The Chinese and Japanese used them in the treatment of goiter and other glandular troubles. The Romans considered seaweeds as useless even though they used them to heal wounds, burns, scurvy, and rashes. The British used *Porphyra* to prevent scurvy on long voyages. Various red algae (particularly *Corallina officinalis*, *C. rubens*, and *Alsidium helminthocorton*) were used as vermifuges in ancient times. Dulse is reported to be a laxative and also to reduce fever. Several red algae (including *Chondrus crispus*, *Gracilaria*, *Gelidium*, and *Pterocladia*) have been used to treat various stomach and intestinal disorders. The algae apparently absorb enough water to relieve constipation and other associated discomforts. One Hawaiian red alga (*Centroceras clavulatum*) was used extensively as a cathartic. The stipes of one large kelp (*Laminaria cloustoni*) have been used to aid in childbirth by distending the uterus during labor. It was also used to open wounds and facilitate healing. Recently a number of species of ma-

[1] *Porphyra* is commonly called "nori" in the orient.—Editor.

[2] The brown algae Laminaria and Undaria are called kombu and wakame, respectively, in the orient.—Editor.

Drying *Laminaria* near the Usu Branch, Hokkaido Central Fisheries Experiment Station, Japan (August 1971).

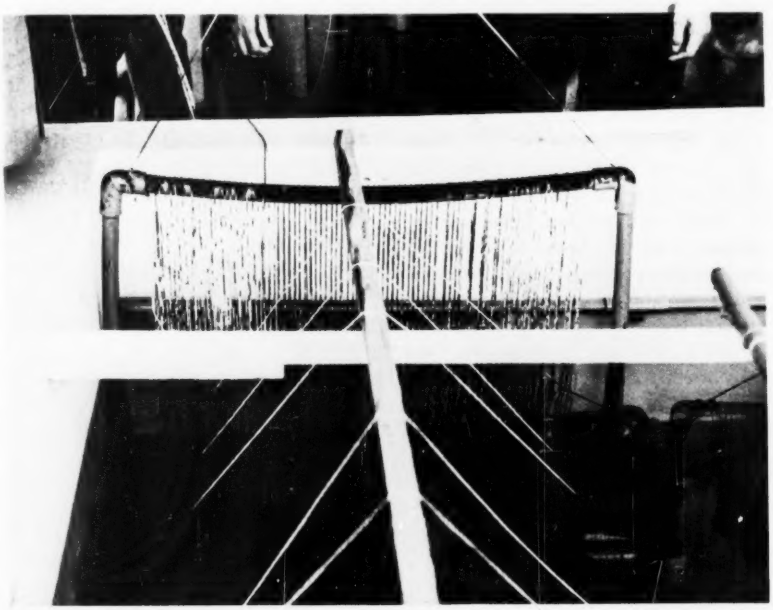
rine algae have been found to have anticoagulant and antibiotic properties. The colloidal extracts (carrageenan) of some red algae may possibly be useful in ulcer therapy, while the colloidal materials of brown algae (alginates) are found to prolong the "rate of activity" of certain drugs.

Phycocolloids, or the naturally occurring storage products (polysaccharides) of seaweeds, are the basis of major industrial utilization of seaweeds. They are also referred to as hydrocolloids, because of their ability to form colloidal systems when dispersed in water. To date, phycocolloids have only been extractable on a commercial basis from the brown and red algae. The principal phycocolloids are algin (from kelps and rockweeds), agar (from *Gelidium* and other related red algae), and carrageenan (from the red algae *Chondrus crispus*, *Gigartina* and related species). Each phycocolloid has characteristics suiting it to particular uses and each can be varied within relatively broad limits by extractive and chemical techniques to adapt it precisely for specific employment.

Algin or alginic acid is prominent in kelps and rockweeds. According to Dawson (1966), it constitutes about 2.5 percent of the total weight in *Macrocystis*. Thus, *Macrocystis* has become the primary source of algin in the United States, because of its ease of harvesting and high content of algin. *Ascophyllum nodosum* and several kelps are used as a source of algin in Europe and other locations.

Several derivatives of alginic acid are known (calcium, sodium, ammonium, potassium, and propylene glycol alginates) and they have a wide variety of uses because of their viscosity and water absorbing properties. Alginates are commonly used as emulsifiers and stabilizers in dairy products, such as sherbets, ice cream, chocolate milk, cheese, puddings, and toppings. They are also used in syrups, sauces, salad dressings, soaps, shampoos, toothpastes, shaving creams, medicines, lipsticks, paints, insecticides, plastics, fireproofing fabrics, and polishes. Some surgical threads are now being made of alginates because they will dissolve after a certain period of time and do not have to be removed. A whole-blood substitute derived from seaweed has been used in emergency transfusions. It is more effective than sugared water or salt water, which are customarily used, because it does not break down in the blood stream.

Carrageenan is another very important industrial colloid. It is primarily obtained from Irish moss and species of *Gigartina*, but it can also be extracted from at least 20 other species of red algae, many of which are found in different parts of the world. At present, Irish moss is one of the major marine resources in New England and the Maritime Provinces of Canada, and it is the basis of an extensive colloid industry. Carrageenan resembles agar chemically (i.e. it is a carbohydrate ethereal sulphate) but it has a higher ash con-



Frames with attached sporophytes of *Laminaria* on twine at the Usu Branch, Hokkaido Central Fisheries Experiment Station, Japan (August 1971). The twine is later tied to heavier ropes and transplanted into the field.

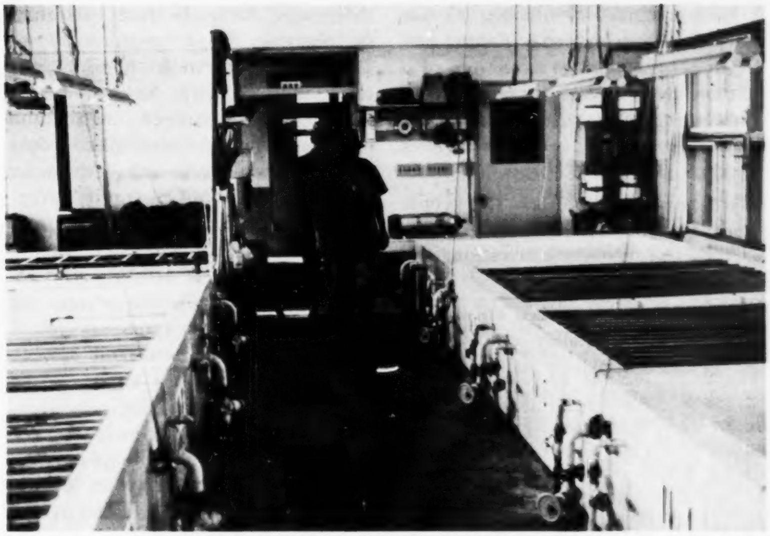
tent and requires somewhat higher concentrations to form a gel.

The colloid extracted from Irish moss constitutes about one-half of the weight of the plants (dry weight basis). Irish moss is worth from 12 to 13 cents per pound, dry weight, but the colloid as extracted, standardized, and blended (i.e. with different carrageenans) costs well over $1 per pound. Despite this relatively high cost, demand exceeds supply. Carrageenan is widely used in the food and pharmaceutical industries because of its thickening, emulsifying, stabilizing, and suspending properties. It is used extensively in milk-based products because of its unique interaction and stabilizing effects with milk protein. Extracts find their way into hundreds of other common household items such as toothpastes, diet foods (the carbohydrate is not metabolized in the human digestive system), hand creams, soups, confectioneries, insect sprays, water base paints, inks, shoe stains, shampoos, and cosmetics. It is also used in the sizing of cloth and thread, in certain printing processes, as a clarifying agent in the production of beer, and as a dental impression compound.

Agar is a gel-forming substance found in certain species of red algae (e.g. *Gelidium*, *Gracilaria* and *Pterocladia*). The name agar is an abbreviation for the Malayan or Ceylonese term agar-agar, which means jelly. A jelly is produced from these seaweeds when they are boiled and the resulting liquid is cooled. Agar was first produced commercially by the Japanese in 1670, and it was the first seaweed product to become an important stable item of commerce. The Japanese are still the primary producers of agar. However, since its acute shortage during the second world war, agar has been produced in substantial amounts by other countries (Britain, Denmark, Australia, United States, Russia, New Zealand, India, and South Africa).

Robert Koch first showed (1881) that agar was an effective culture media, because many microorganisms were unable to decompose it. Thus it has become a standard fixture in most hospitals and laboratories where culture media are required. Agar was early found to be useful for stomach and intestinal disorders. It is a non-irritant bulk producer which absorbs and holds water as well as serving as a mild laxative. It is now employed as a covering for various capsules (antibiotics, sulpha compounds, and vitamins) when a slow release of the medicant is desired at a point beyond the stomach. Agar preparations are sometimes used beneath bandages to heal wounds. In addition it has a variety of other uses: preservation of canned meats, fish, and other easily spoiled foodstuffs; preparation of sizing for fabrics; as an ingredient of waterproof paper, waterproof cloth, and glue; a cleaning media; a clarifying agent in the manufacturing of wines, beers, and coffee; and the preparation of special breads for diabetics in which agar replaces the starch.

As suggested by Scagel (1961) carrageenan and algin have many similar uses. However, they have specific properties which restrict or enhance their use depending on the circumstances.



Tanks and culture frames inside the Usu Branch, Hokkaido Central Fisheries Experiment Station, Japan.

SEAWEED AQUACULTURE—AN OVERVIEW

Krishnamurthy (1965) gives an interesting account of the principles and problems associated with seaweed cultivation. He emphasizes that cultivation of many species would be desirable in order to maintain adequate supplies of raw materials. A knowledge of the plant's biology and reproduction is fundamental to successful cultivation. Most seaweeds produce an enormous number of spores, and they can be multiplied extensively if proper culture conditions are perfected. For example, over a million swarmers can be produced from a single *Ulva fasciata* plant, while a single *Gracilaria millardetii* plant produces over 60,000 tetraspores and more than 40,000 carpospores (Krishnamurthy, 1965).

In contrast to sporic reproduction, the number of fragments that can be produced from a plant is limited by its size, maturity, and physiological state. According to Austin (1960) there are a variety of adaptive features that allow free-living seaweeds, such as *Furcellaria*, *Gracilaria*, *Gelidium*, *Pterocladia*, *Eucheuma*, and *Hypnea*, to survive in a pelagic state: (1) they can grow without orientation to light and gravity; (2) they are capable of rolling; (3) they can survive burial in mud and/or sand; and (4) they can carry out constant vegetative multiplication, without the loss of clonal vigor. Many of the latter properties should be screened in "seed" stock selection of seaweeds for aquaculture.

Krishnamurthy (1965) lists six major problems which may restrict seaweed cultivation: (1) selection of a suitable environment for growth; (2) engineering of the seashore for farming; (3) protection of the crop from physical and biotic effects; (4) probable pests and parasites; (5) proper transplantation of the young germlings to the field for cultivation; and (6) harvesting.

In Japan most seaweed cultivation is carried out in shallow embayments and inland seas where reduced wave action is present. Sheltered habitats have obvious advantages, for they minimize the structural support needed for culture frames such as "hibi," or the nets and posts employed by the Japanese in nori cultivation. Sheltered habitats will also avoid the dislodging of germlings and other propagules. However, sheltered embayments are often highly polluted in industrialized countries, and they may have wide ranging hydrographic regimes (temperatures and salinities), both of which may restrict the growth of seaweeds. A thorough understanding of the environmental tolerances and optima of seaweeds is fundamental to successful seaweed mariculture. Protection of crops from biological (i.e. grazing) and physical effects may also be a major consideration in seaweed cultivation. Extensive fish and urchin grazing (Randall, 1965; Leighton, Jones, and North, 1966) are known in many areas, and they can easily destroy a large-scale seaweed farm. Other predators, pests, and parasites such as fungi and bacteria could also cause epidemic destruction of unialgal seaweed farms.

Adequate harvesting techniques must be devised for each of the different types of seaweeds. Ideally one would like to maintain a farm with a continuous supply of "seed" material. Seaweed farming from vegetative fragments has many potential advantages, if successful crops can be harvested and residual "seed" material is retained for further regeneration and growth. In sporic propagation of seaweeds, advantage should be taken to maintain peak populations. The effects of differential levels and times of harvesting should also be determined for each species in order to maintain peak productivity of seaweeds. In addition, breeding and selection studies will be fundamental to successful seaweed mariculture programs. Specific examples would be genetic studies to enhance disease resistance or to select specific properties (Suto, 1963).

A precaution of major significance is to avoid careless handling of "foreign" seaweed strains, to prevent the introduction of less exotic species of algae and/or animals (Hanic, 1973). Examples that can be cited are the recent introduction of *Sargassum muticum* to the Pacific Northwest (Scagel, 1956) and to Great Britain (Farnham, Fletcher, and Irvine, 1973; Anonymous, 1973), as well as the recent transfer of *Codium fragile tomentosoides* to the northeastern coast of North America (Coffin and Stickney, 1966). Presumably both of the latter seaweeds were introduced with shellfish from other geographical areas.[3] *Codium fragile* is a major pest, for it has destroyed many of the commercial oyster beds in New York and New England. Hanic (1973) emphasizes that adequate precautions will be expensive and time consuming, because "foreign" strains must be quarantined until they are decontaminated. All waste seawater involved in such impoundment cultures should obviously be sterilized to prevent contamination of local waters.

Calhoun (1968) gives an interesting account of the systems approach to food production from the sea. He emphasizes that one should take advantage of all natural opportunities available, and attempt to adjust nature to increase yields. Calhoun cites nutrients as a means of increasing yields. The enhancement of seaweed growth by supplying nutrient-rich deep water should be cited as a possible application in aquaculture. Roels, Gerard, and Bé (1969) give a detailed account of artificial upwelling and its application to shellfish mariculture. In addition Roels has suggested its applicability to seaweed mariculture (O.A. Roels, Lamont-Doherty Geological Observatory, Palisades, NY 01964, pers. commun.).

In the continental United States, legal and sociological considerations would appear to be two of the major hindrances for active seaweed aquaculture. The concept of multiple use and public ownership must be thoroughly integrated into any successful program of seaweed mariculture. Kane (1970) gives a detailed review of ocean law and its applicability to aquaculture. Claims and decisions

[3]The means by which *Codium* was introduced into New England waters is disputed by the scientist responsible for introducing the European oyster, *Ostrea edulis*, (Introduction of *Codium* in New England Waters, V. Loosanoff, Fish. Bull. 73:1, Jan. 1974. In press.). Loosanoff points out the detailed precautions taken to prevent introduction of foreign organisms with the European oysters and speculates that *Codium* was introduced during World War II via European freighters heavily encrusted with marine fouling organisms (as much as 2-3 ft thick) in which *Codium* was both present and visible. —Editor.

Poles suspending shells with conchocelis, inside the Usu Branch, Hokkaido Central Fisheries Experiment Station, Japan.

involving riparian landowners, navigation, fishing, recreation, and water quality are discussed.

SEAWEED CULTIVATION

Nori

Porphyra, or nori as it is commonly called in the orient, was first cultured in Tokyo Bay in 1736 by positioning well-branched trees or bamboo in the sea bottom to capture the spores (Okazaki, 1971). Subsequently, other "culture" methods have been perfected by the Japanese, such as blowing up rocks on the sea bottom, the introduction of rocks and oysters in the ocean and in tanks, and the seeding of nets attached to poles (i.e. "hibi"). The discovery of the microscopic conchocelis stage of *Porphyra* (Drew, 1949, 1954) initiated a rapid development of nori cultivation. Thus, in 1952 16,000 acres of nori were under cultivation in Japan, while in 1959 over 155,000 acres were cultivated (MacFarlane, 1968). At present the nori industry employs over 300,000 Japanese (Neish, 1968).

MacFarlane (1968), Bardach et al. (1972), and Tamiya (1959) give detailed accounts of modern nori culture in Japan. Cleaned oyster shells are primarily used as spore (carpospore) collectors from the leafy thallus of *Porphyra*. The shells are suspended for a few days in shallow trays with *Porphyra* plants. Subsequently they are allowed to incubate for 7-8 months (March through September), during which time the carpospores attach and produce the microscopic conchocelis stage. In October the conchocelis stage usually produces conchospores (monospores), which are buoyant; the conchospores are transferred to the hibi and allowed to adhere. After a month the nets are transferred into the ocean and allowed to grow from about November to March. The hibi are usually placed at the mouths of estuaries where the waters are nutrient-rich. Sometimes the conchospores are collected in the field by placing conchocelis-bearing shells beneath the collecting nets and allowing them to set. *Porphyra tenera* is the most important commercial species of nori. However, four other species (*P. angusta, P. kunieda, P. yezoensis*, and *P. pseudolinearis*) are also cultivated. The seasonal cycle and growth of the five species are somewhat different, as well as their preference for open coastal versus estuarine habitats (Boney, 1965).

According to MacFarlane (1968) there are three critical periods in the life history of nori: (1) adhesion of the conchospores to the hibi; (2) the initial stage of growth after "budding" of the conchospore; and (3) the initial period of harvest. Temperatures of about 21.7°C are optimal for adhesion of the conchospores. In contrast temperatures of less than 13.1°C are critical for the "budding" of the conchospores. Boney (1965) states that water motion is also very important in determining spore attachment, for currents greater than 7 cm/second will inhibit attachment of conchospores.

A variety of spore-collecting machines have been produced to disperse the buoyant conchospores from a drum onto nets (MacFarlane, 1968). The nets are typically 4×60 ft, with from 6- to 10-in meshes. Particular attention is paid to reduce crowding, for crowded plants are more susceptible to fungal (e.g. *Pythium*) and bacterial diseases. Thus, 10-50 conchospores/cm is about the ideal number of spores; higher numbers are associated with fungal and bacterial diseases. The vertical positioning of the hibi can also reduce disease. Typically the plants are positioned for 3-4 hours of exposure/day. Higher intertidal exposure periods have been found to decrease fungal diseases. However, too much exposure may reduce growth and toughen the thallus, making it unsuitable for food (Bardach, et al., 1972).

A variety of fertilizer pellets (90 percent nitrogen and 10 percent potassium) are now being developed to provide fertilization of nori populations (MacFarlane, 1968). The pellets are placed in porous containers in amounts to provide 10-14 days of fertilization. Fertilization is also being used in some areas in preharvest periods to increase coloration.

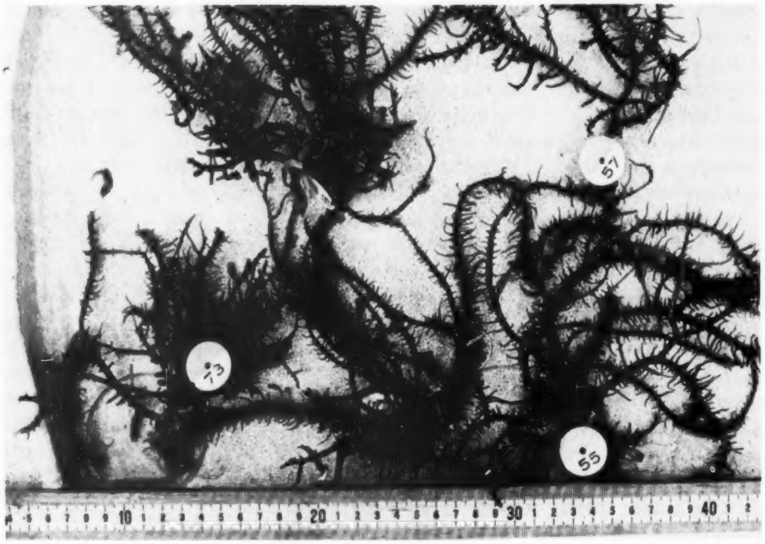
According to Okazaki (1971) young leafy thalli of *Porphyra* 2-3 cm long can be stored for nearly a year if they are freeze-dried (to 20-30 percent of original water) and refrigerated to −20° or −30°C. If they are put back into seawater they can produce a crop in about 1½ months. In 1970, one-half of all culture nets were refrigerated. The phasing of cultures has obvious advantages of prolonging the harvesting season of good quality nori. Another method of major interest is the photoperiodic control of conchospore liberation from conchocelis. Several experiment stations in Japan control (phase) the liberation of conchospores to control the yields of nori (MacFarlane, 1968). According to Bardach et al. (1972) about 70 percent of the commercial production of nori in Japan is based on artificial production of monospores (conchospores) by various prefectural and municipal laboratories.

Breeding experiments have been initiated to enhance the edible properties of nori (Suto, 1963). On the whole these have not been very successful (Boney, 1965).

Bardach et al. (1972) have given an economic evaluation of the nori industry in Japan. Typically an 18-m culture net produces from 35 to 105 kg of nori annually. In some areas as many as 100 nets/hectare can be found that are capable of producing about 750 kg/hectare during the 6-8 month growing season. Since 1960 the annual production of nori in Japan has averaged about 120,000 metric tons; the supply seldom equals the demand. Imada, Saito, and Teramoto (1972) state that the annual sales of nori during 1970 were about US$140 million (based on the then-prevailing currency exchange rate). This is higher than any other marine product in Japan. Inshore pollution is a major problem limiting the production of nori, and the Japanese are seeking foreign sources of *Porphyra*.

Wakame and Kombu

The brown alga *Undaria*, or wakame as it is commonly called, is one of the most important edible seaweeds in Japan. Three species of *Undaria*, *U. undarioides*, *U. peterseniana* and *U. pinnatifida*, are cultured in Japan. In the early 1960's over 60,000 tons were produced (Okazaki, 1971).



Samples of Florida *Eucheuma* sp. employed by C. J. Dawes in growth and transplant studies, Florida Keys, November 1971.

MacFarlane (1968), Okazaki (1971), and Bardach et al. (1972) give detailed accounts of wakame propagation in Japan. "Stone planting" and "rope cultivation" are the two major methods of culturing. With the first method stones or concrete blocks are deposited on the sea bottom for the attachment of kelp zoospores and the subsequent growth of sporophytes. The method is most successful in areas where large quantities of *Undaria* are growing.

The concrete blocks are cylindrical in shape, with a basal opening and a well-shaped depression at the top. The basal opening lessens the shifting of the blocks due to wave action, while the upper depression provides increased surface area and shelter for the growth of young germlings. The blocks are harvested after a year and replaced by new ones. The Japanese government has subsidized the production of the blocks in some northern sections of Hokkaido.

The rope cultivation techniques were first perfected at Onagawa, in the Sendai region of northern Honshu (Bardach et al., 1972). The techniques are currently employed at various prefectural and municipal laboratories, as well as by private growers throughout Honshu. *Undaria* is a cold-water alga, hence, it can only be cultivated where persistent cold water conditions are prevalent (i.e., northern Honshu), or when winter temperatures are below 22°C i.e., in southern Honshu.

Typically the twine or rope is immersed in seawater tanks with fertile kelps during April and May The zoospores are allowed to settle for 2-3 hours, or until about 100 spores/cm of twine have adhered. Populations with higher densities tend to suffer from fungal or bacterial diseases. After spore attachment, the twine is lashed to frames and retained in deep seawater tanks—until about September to November. The young sporophytes are then transported into the field. The twine, with its attached sporophytes, is wound around heavy gauge "growth" ropes, which are about 3 m long. The "growth ropes" in turn are attached to a horizontal bamboo pole, which is kept afloat by buoys and anchored at the bottom. Cultures of *Undaria* can be grown at any depths to 6 m (Bardach et al., 1972). Pearl culture rafts may also be employed to culture wakame. The young kelp sporophytes can be harvested by mid to late winter.

Bardach et al. (1972) summarize a variety of production data for wakame cultivation. For example one bamboo raft, 3.6×1.8 m, can produce about 1 ton wet weight of *Undaria*. The annual production of wakame in Japan is presently estimated to be about 60,000 metric tons. According to the same authors there is some conflict of interest between the oyster and wakame industries, because they both employ similar types of environments.

Okazaki (1971) describes two other cultural techniques for wakame production besides "stone planting" and "rope cultivation." The first is the removal of miscellaneous seaweeds by divers or specialized machinery. Chapman (1950) also describes the "weeding" of Japanese kelp beds to reduce unwanted species. A second method of enhancing wakame growth is by exploding the sea bottom with dynamite. By this method new rock surfaces appear to which zoospores of *Undaria* can adhere.

The brown alga *Laminaria* or "kombu" is another major edible seaweed in Japan. In addition it is also a source of alginic acid. *Laminaria japonica* is the major source of kombu in Japan, but several other species of *Laminaria* are also employed. "Stone planting" and "rope cultivation" are the two primary means of propagating kombu. MacFarlane (1968) gives a complete account of *Laminaria* cultivation in Japan. The techniques employed are similar to those of wakame described previously. Two to three year old plants are considered suitable for harvesting. In some areas rock ledges are blasted with dynamite in order to produce new surfaces for *Laminaria* growth.

Artificial propagation of *Laminaria japonica* in China has been enhanced by detailed ecological studies (Bardach et al., 1972). Light studies have shown that the young sporophytes grow best at 1,000-2,000 m-candles or 0-1.5 m below the surface. Nitrogen appears to be a major factor determining the growth of *L. japonica*, for it flourishes naturally in enriched habitats (i.e., those with more than 5 mg N/m^3 of nitrate-nitrogen). Hence, fertilization with nitrogenous fertilizers is an integral part of the cultivation procedures. *Laminaria japonica* is a cold-water species that grows successfully at temperatures as high as 21.5°C. An understanding of the temperature requirements and the

development of warm water strains, called "Hai-Ching #1," have made it possible to grow *L. japonica* in southern China during the spring and winter months. The development of long-range shipping techniques, employing low temperatures (5°C), aeration, and complete darkness, have also allowed the transportation of young, mature, and reproductive sporophytes.

Cheng (1969) and Bardach et al. (1972) give a detailed account of *Laminaria japonica* propagation in China. Prior to 1943 "stone planting" or simple bottom culture techniques were employed. Since 1949 a variety of raft culture techniques have been developed as follows: (1) basket rafts with five or more cylindrical bamboo baskets are tied in a row for cultivation; (2) a single line tube raft is constructed of bamboo or rubber tubes and tied end to end; and (3) a double line tube raft is constructed from bamboo tube to form a ladder-like structure. Ropes bearing young sporophytes are attached to the rafts. The ropes are either attached perpendicular to the water, parallel or upright. The latter method provides maximum access to the sunlight. In most cases the plants are established in the field from February to March. By mid-June they are large enough (3 m or larger) to harvest.

A porous earthenware cylinder containing fertilizer is attached to each of the culture rafts. The fertilizer becomes dispersed in the water and it is absorbed by the sporophytes. In some cases the young sporophytes are immersed in a solution of ammonium nitrate prior to being outplanted; immersion in a fertilizer solution may also be carried out weekly to enhance growth.

The single line tube raft is the most popular type of cultivation method for *L. japonica* because it produces the highest yield of seaweed/kg of fertilizer, i.e., 3.75 kg of algae/kg of fertilizer. As many as 72,000 to 134,000 kelp plants/hectare can be cultured on the single-line tube rafts.

The original "stone planting" techniques in China simply provided additional substrate for naturally produced zoospores. The zoospores are now allowed to attach to the stones prior to deposition. In many areas 3,800-4,200 stones/hectare are planted for the growth of *Laminaria japonica*.

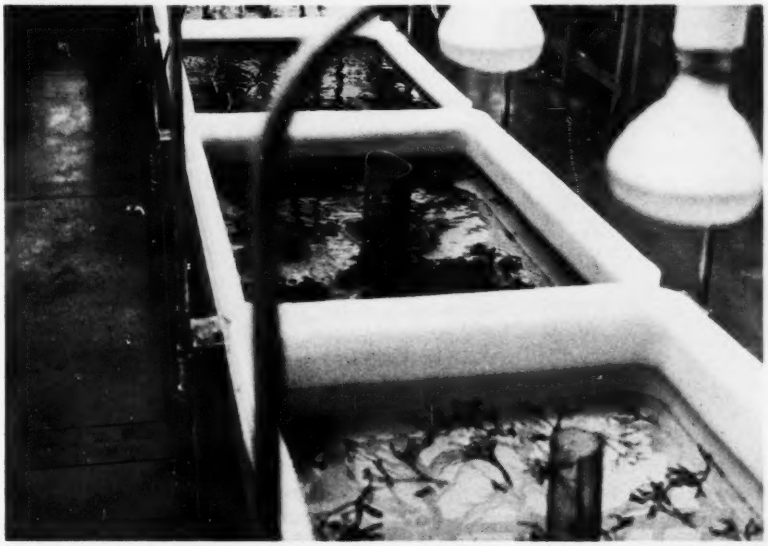
According to Bardach et al. (1972), bottom cultures in productive areas yield about 2.4 metric tons/hectare. Yields for raft cultures are not available, but they must be higher than those on the bottom. As of 1960, 3,000 to 5,500 hectares of coastal waters were utilized for the cultivation of *L. japonica* in China.

Monostroma and *Enteromorpha*

The green algae *Monostroma* (Hetoegusa), *Enteromorpha* (Aonori) and *Ulva* (Aosa) are the most important edible green algae in Japan (Okazaki, 1971). *Monostroma* is extensively cultivated, while *Enteromorpha* is grown to a lesser extent (MacFarlane, 1968). *Ulva* is only occasionally used as a food source, and it is rarely cultivated. *Monostroma* commands the highest price of any seaweed in Japan (Bardach et al., 1972). The cultivation techniques for each of the three green algae are basically similar to those of *Porphyra*. That is, they are grown on "hibi," which are positioned in the intertidal zone of shallow seas and estuaries. According to Boney (1965) the origin of *Monostroma* cultivation appears to lie in the plants growing as contaminants on the *Porphyra* "hibi." *Monostroma* is presently grown by itself, or mixed with *Porphyra*, *Enteromorpha*, and/or *Ulva*. Certain of the *Monostroma* culture grounds are called "taneba," for these sites are where the fixed spores and germlings appear in appreciable quantities in early autumn (Boney, 1965). According to Segi and Kida (1960) the position of the "taneba" is linked to the direction of the main surface currents of the flood tides. As many as three crops of *Monostroma* are harvested from a net before it is replaced (Bardach et al., 1972).

Gelidium, *Pterocladia*, and *Gracilaria*

As suggested previously, Japan is the primary producer of agar. *Gelidium amansii* is the principal agar source in Japan, but a variety of other species of *Gelidium*, *Pterocladia*, and *Gracilaria* are also utilized. Most of the latter seaweeds are obtained by dredging and diving in natural beds. The Japanese also propagate *Gracilaria* on nets and ropes in sheltered embayments such as Tokyo Bay. Branches of the plant are placed at intervals in the twists of the ropes, and they are in turn suspended in the nutrient-rich waters. Later the ropes are pulled up and harvested.



Greenhouse culture tanks with *Furcellaria fastigiata* (first tank) and *Chondrus crispus* (second and third tanks) at the National Research Council of Canada's Research Facility at Fink Cove, Nova Scotia, Canada (summer 1971).

The regenerative properties of *Gelidium amansii* and related forms have been utilized as a means of increasing the natural yields of the plants. Basically small fragments of the plants are scattered in bays where they are allowed to regenerate new fronds. The latter technique has been employed for many decades (Okamura, 1911). More recently "rope concrete cultivation" has been used for the propagation of *Gelidium amansii* (MacFarlane, 1968). Basically the concrete structures are similar to those employed by the Japanese for wakame cultivation, except that they are pyramidal rather than cylindrical in shape and they have a series of eyebolts embedded at different elevations. Ropes are pulled through the eyebolts to retain the fragments. Again the regenerative properties of the plants are employed to "culture" the plants on the concrete blocks. According to MacFarlane (1968) a variety of fertilizer pellets containing urea, phosphates, and indole acetic acid are now being developed to enhance the growth of *Gelidium* and other agarophytes.

Chondrus

The Atlantic Regional Laboratory of the National Research Council of Canada in Halifax has recently initiated an extensive program of marine Irish Moss cultivation (Neish, 1968). The experimental site is located about 18 miles from Halifax. It consists of several greenhouses, huts, and tanks (outdoor and indoor) with a constant stream of water. Studies of seaweed growth, reproduction, and stock selection have been initiated.

Neish and Fox (1971) describe a variety of greenhouse experiments on vegetative propagation of *Chondrus crispus*. Detached plants (i.e., plants lacking holdfasts) are capable of continuous growth when held in greenhouse tanks supplied with flowing seawater. Growth rates were assessed under different light intensities, aeration, photoperiods, as well as varying concentrations of several nutrients. Nutrients (calcium nitrate, urea, diammonium phosphate, and superphosphates) were supplied by pulse feeding with different fertilizers or by the slow addition of nutrients in plaster of paris pellets. Calcium or sodium nitrate and ammonium nitrate stimulated growth and enhanced pigmentation. Urea was a poor source of nitrogen. Continuous illumination and high temperatures (15-20°C) gave the fastest rate of growth. Growth was exponential with doubling times occurring in 2-3 weeks.

A selection of rapidly growing strains was initiated by Neish and Fox (1971). One strain (T-4) not only grew faster than others, but it was less susceptible to epiphytization, which was a major problem in some experiments. Pieces of fronds from a large plant (T-4) typically showed an enhancement of growth until the plant became quite large. Neish and Shacklock (1971) studied the successional development of a clone from the T-4 strain. A single clone was grown from 4.5 g on 1 May 1970 to a total biomass of 1 ton by September 1972. Typically the detached plants assume a dense spherical shape and they remain vegetative. The larger plants spontaneously fragment, particularly when phosphorous is limiting.

Further experiments on vegetative propagation of Irish moss strain T-4 are described by Neish and Shacklock (1971) and Shacklock, Robson, Forsyth, and Neish (1973). The effects of differential flushing rates, combinations of fertilizers, population densities, additions of carbon dioxide, and light quality are summarized. Of particular interest was the finding that the chemical composition of cultured plants could be altered by changes in culture conditions. Thus, plants growing rapidly in nitrogen-enriched seawater have a low content of total solids and carrageenan, and a high content of nitrogenous materials. When nitrogen-enriched plants are transferred to unenriched sea water there is a rapid increase in percent carrageenan and total solids and a decrease in nitrogen compounds. Thus, a "ripening" or "fattening" period with no nutrients should be incorporated in any aquaculture program with *Chondrus crispus*. Wild plants growing *in situ* also go through these same changes during the summer when nitrogen is low (Fuller and Mathieson, 1973). Temperature also has an effect on these changes, for the temperatures which produce the best growth with fertilizers give the best carrageenan yields (Shacklock et al., 1973).

Chen, McLachlan, Neish, and Shacklock (1973) have recently shown that kappa carrageenan is found in the gametophytic plants of Irish moss, while lambda carrageenan is present in the sporophytic phases. Kappa carrageenan is the major gel fraction from Irish moss (Stancioff and Stanley, 1969). As suggested by Shacklock et al. (1973) "seed" selection of differential phases would provide a uniform and consistent supply of the different carrageenan fractions.

Neish and Fox (1971) discuss the application of their work to commercial cultivation of Irish moss. They state that it would not be profitable as a greenhouse crop, nor in a system employing supplemental artificial illumination. However, cultures in outside impoundments might be profitable from May to September at their latitudes. Adequate nutrients (particularly nitrogen sources), controlled access to sea water, temperatures greater than 10°C, and the availability of superior strains would be essential.

Macrocystis

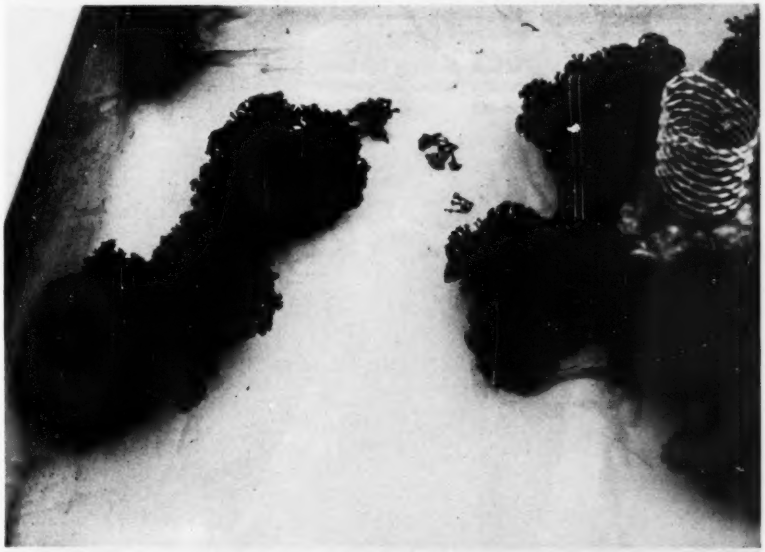
Macrocystis pyrifera is one of the most important natural resources on the California coast, for it is a major source of algin as well as a significant component of the nearshore kelp bed community (North, 1971). A rapid deterioration of kelp beds has occurred in southern California since 1940, and it has caused considerable concern for the welfare of this valuable resource. An intensive study was conducted by North and his associates from 1956 to 1962 to determine the cause of the kelp decline (North, 1971). One of the major findings was that excessive grazing by sea urchins (*Strongylocentrotus purpuratus*) was destroying many beds. The urchins were so numerous that reforestation was not occurring; the imbalance of urchins was primarily due to the absence of an important predator, the sea otter. In 1962 a new project, "The Kelp Habitat Improvement Project," was initiated in order to control urchin populations and to restore the vanishing kelp beds.

Close-up photo of *Chondrus crispus* in the greenhouse at the National Research Council of Canada's research facility at Fink Cove, N.S. Note the spherical, compacted shape of the plants.

North (1972, 1973) gives a detailed description of *Macrocystis* cultivation and the habitat improvement studies since 1962. A natural evolution of mariculture techniques has developed. Initially transplant techniques were attempted with large *Macrocystis* plants (North, 1964). It was hoped that a natural "seeding" of adjacent areas would occur and that the beds would be "reforested." The transplants were very laborious and the plants were rapidly eaten by resident urchins and/or fish populations. Direct killing of urchins by hammers was attempted to reduce urchin populations and allow new colonization of *Macrocystis* plants. This was a very time-consuming operation, and ultimately quicklime was used prior to transplanting, for it kills urchins immediately upon hitting their tests. Some restoration of beds ultimately occurred by transplantation and continual application of quicklime.

Ultimately mass culture techniques were evolved and microscopic sporophytic stages were used as "seed" for natural "reforestation" (North, 1972). The embryonic sporophytic stages of *Macrocystis* have a "sticky" exterior; thus, they are cultured until they exhibit a sticky outer surface. Then the cultures are scraped free and dispersed in the sea. Quicklime is again used to kill the sea urchins prior to "seeding." The results of a "seeding" operation are not evident until 3-4 months after their dispersal. Six to nine additional months must elapse before a juvenile kelp develops sufficient surface canopy to be visible.

A variety of other dispersal techniques were attempted (North, 1972, 1973). In some cases the "sticky" sporophytes were bathed with lead particles to aid with dispersal and to provide negative buoyancy. Mass cultures have also been initiated on a substrate of glass cloth. The cloth is 18 inches wide and of varying lengths up to 30 feet. A dense spore suspension is introduced to the holding aquarium and allowed to settle on the cloth for several days. After being well established the cloth is maintained in a chilled, filtered, and ultraviolet sterilized flowing seawater tray. After 1-2 weeks the embryonic sporophytes are visible. Their surfaces are sticky at this time and they can be dispersed into the sea. Dispersal involves scraping the tiny plants off the cloth near the bottom by a scuba diver. Recently an attempt has been made to grow kelp juveniles on plastic (PVC) rings, with a ¼- to 12-inch diameter. Ultimately, the rings with their attached embryos are glued by an epoxy resin to a rocky bottom. The latter method was not very successful, because several starfish were attracted to and ate the epoxy, as well as the kelp sporophytes. North (1973) gives a detailed account of the kelp culturing system his group has developed for mass culture of "seed." The transplants of kelp embryos on strips of glass cloth are similar to the "rope culture" techniques developed by the Japanese for wakame and kombu.



Close-up photo of *Chondrus crispus* in tanks at the National Research Council of Canada's research facility at Fink Cove, N.S.

Close-up photo of *Furcellaria fastigiata* at the National Research Council of Canada's research facility at Fink Cove, N.S.

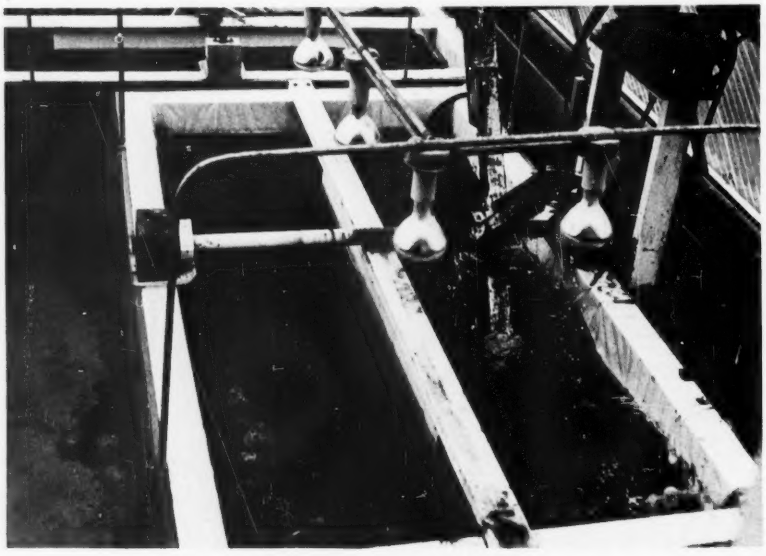
Fish and urchin grazing often restricted the transplantation and "reforestation" of kelp plants. According to North (1973), about 2,000 adult plants are needed to stabilize and survive grazing, as well as to overcome stress conditions associated with storms. An attempt was made to reduce fish grazing by establishing a "kelp nursery" enclosed within a tent. A 4-inch mesh was employed. The nurseries were only partially successful, for they did not exclude the smaller fish. A 1½-inch mesh is now being employed. Estimations of fish grazing showed that three adult kelps/fish was a relatively stable condition. It was estimated that a biomass increase of about 600 kg/day of kelp was needed to prevent fish depletion. The transplantation of large *Macrocystis* plants was found to attract many herbivorous fish and urchins. Even so it was found that fish grazing was more important in certain areas than urchin grazing.

North (1973) emphasizes that he is attempting to develop "seeding" techniques which are economically feasible for use in the United States—i.e., with its high labor costs. He estimates that an average survival rate is 1/100,000 with their present techniques. Thus, their culturing techniques are being developed to produce billions of embryos at a very inexpensive price.

Another major area of *Macrocystis* work has been an attempt to select heat-tolerant strains, for abnormally high temperatures can cause kelp decline. Heat-tolerant strains appear to exist, particularly in more southerly areas, and they show good potentials as transplants (North, 1971).

Eucheuma

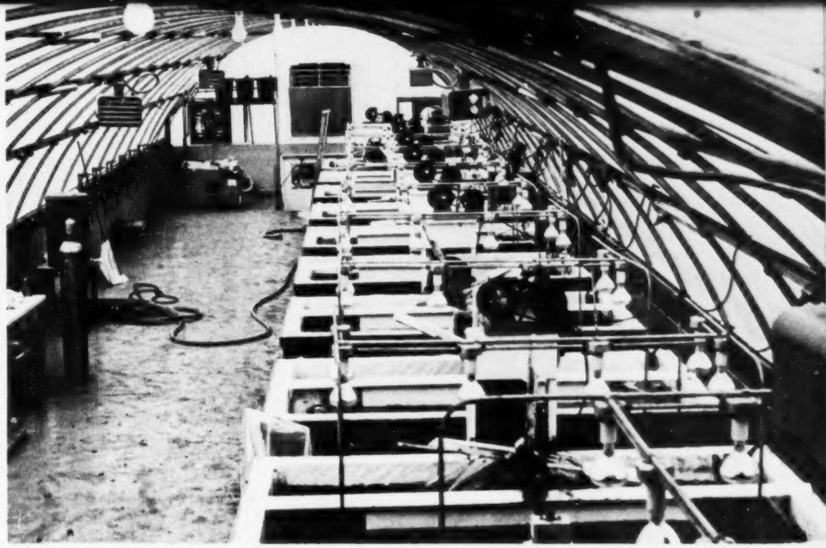
The tropical red algal genus *Eucheuma* is another major source of the phycocolloid carrageenan. According to Doty (1970, 1973) the genus can be divided into groups; the *cottonii* types that contain iota carrageenan in their cell walls and the *spinosum* types that contain kappa carrageenan. Iota carrageenan disperses quickly into cold water, and it does not form as rigid a gel as kappa carrageenan. Iota carrageenan has many industrial applications. The major source of *Eucheuma* is in Southeast Asia and the demand for its extracts, particularly iota carrageenan, exceeds the supply. Overharvesting and variability of wild-crop procurement have encouraged the development of *Eucheuma* mariculture.



Close-up photo of tank and *Chondrus* plants inside the greenhouse at the National Research Council of Canada's research facility at Fink Cove, N.S.

Doty (1973) and Parker (1974) give detailed accounts of *Eucheuma* farming in the Philippines and Micronesia. Successful farms were evolved after a variety of different propagation methods, growth studies, and environmental investigations were conducted on *E. striatum* and *E. spinosum*. Grazing by fish and sea urchins was a major factor restricting direct planting on reef bottoms. Thus, constant-level plant techniques were developed, where the plants were held at a constant distance from the bottom. "Seed" or pieces of fronds weighing 50-150 g are tied to the mesh intersections of monofilament nets with soft polyethylene strips. The nets measure 2.5×5 m, and they have a mesh size of 25 cm². The nets are tied to mangrove poles, which in turn are supported by galvanized wire. The system of nets and poles is very similar to the Japanese "hibi," except for the dimensions and the monofilament lines. About 10 kg of *Eucheuma* are planted on a single net. Typically the nets are arranged in four modules with 800 nets each; the four modules make a 1-hectare farm.

According to Doty (1973) the cost for installing and operating a 1-hectare farm in the Northern Sulu Sea area of the Philippines is about US$3,126/year based on a 3-year amortization. Other costs (i.e., overhead) are variable depending on the location and personnel. About 10 tons of dry weed/hectare has been produced at Tappan, leaving 50-100 g of live weight of each thallus for "seed." It is estimated that 30 tons is reasonable on a well kept farm. Clean *Eucheuma* yields about $250-$300/ton (dry) FOB Manila. Thus, Doty (1973) states that "on a given area, *Eucheuma* farming can provide more than three times the dollar return that sugar brings."



Interior of greenhouse at the National Research Council of Canada's research facility at Fink Cove, N.S. showing tanks, lights, and paddle-wheel system for aeration.

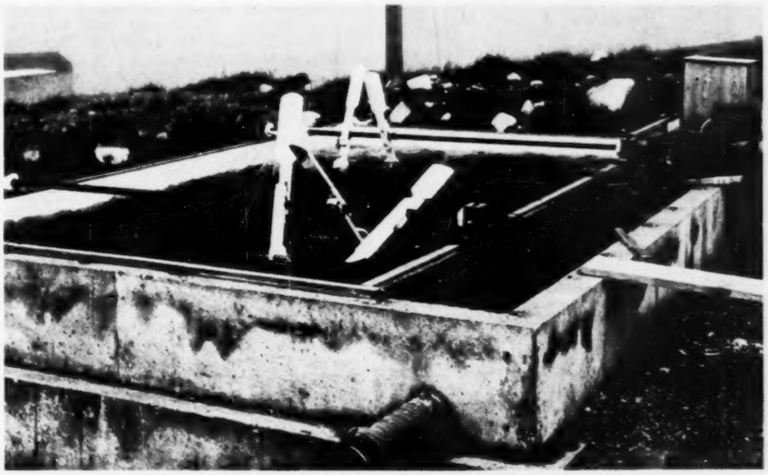
SEA GRANT PROJECTS

A variety of Sea Grant projects are currently being conducted in order to provide basic information for enhanced industrial utilization and mariculture of economic seaweeds. Doty's and North's projects have been discussed in an earlier section and they need not be reviewed. The accomplishments of several other investigators are relevant to our discussion of seaweed aquaculture.

Dawes and his associates at the University of South Florida in Tampa (Dawes, Mathieson, and Cheney, in press; Dawes, Lawrence, Cheney, and Mathieson, in press; and Mathieson and Dawes, in press) have conducted a variety of detailed autecological studies of Florida *Eucheuma* species, particularly *E. isiforme*. As suggested previously, the latter genus has great economic potential as a source of iota carrageenan. Thus, Dawes, Mathieson, and Cheney (in press) have evaluated the feasibility of its culture in Florida, because of the more stable socioeconomic climate in Florida than in the Indo-Pacific area. H. Humm has initiated a variety of culture studies of agar (*Gracilaria*) and carrageenan-producing species (*Hypnea*) of the West Florida area (H. Humm, University of South Florida, St. Petersburg, Fla., pers. comm.). Specifically he has attempted to increase the amount of solid substrate for "seeding" economically important species. In addition he has attempted to develop culture techniques for the production of loose algae in impounded areas. Studies by M. B. Allen and C. P. McRoy at the University of Alaska have attempted to determine the feasibility of cultivating *Porphyra* (or nori) in Alaska. A good market would exist for nori in Japan and other oriental countries.

Waaland (1973) has summarized a series of ecological studies on the Pacific Northwest carrageenophytes *Iridaea cordata* and *Gigartina exasperata*. He describes the development of a simple transplantation method, as well as the results of laboratory findings on optimal light and temperature conditions for sporeling growth. He emphasizes that such information is fundamental if the plants are to be successfully cultivated. Norris and Kim (1972) give a detailed account of thallus development in some of the Puget Sound Gigartinaceae. A thorough understanding of harvesting effects and regrowth potential is basic to successful management of an economic marine crop such as *Iridaea cordata*. Mathieson and associates at the University of New Hampshire have also evaluated the ecology, physiology, reproductive biology, biochemistry and optimal environmental factors for the growth of *Chondrus crispus* and *Gigartina stellata* (Mathieson and Burns, 1971; Burns and Mathieson, 1972a, b; Fuller and Mathieson, 1972; Mathieson and Prince, 1973). Both of these species are harvested in mixed lots as a source of carrageenan in the North Atlantic. An economic evaluation of the Irish moss industry, including its potential for aquaculture, has been outlined by Patell (1972).

Neushul and his associates at the University of California at Santa Barbara have initiated a wide variety of studies of seaweeds, in order to increase their available supply and utilization (M. Neushul, University of California at Santa Barbara, Santa Barbara, Calif., pers. comm.). Detailed studies of spore ecology have been conducted, including the determination of settling rates and the effects of water motion on germination and growth of spores (Charters, Neushul, and Coon, 1972; Coon, Neushul, and Charters, 1972; Neushul, 1972). A resource management study of the agarophyte *Gelidium robustum*



Exterior culture tank at the National Research Council of Canada's Fink Cove, N.S. research facility, showing the concrete foundation and paddlewheels for aeration.

has been conducted (Barilotti and Silverthorne, 1972) to determine optimal time of harvesting, regrowth and reproduction potential after harvesting, and seasonal agar production. Detailed economic studies (e.g. Silverthorne and Sorensen, 1971) have also been initiated in order to determine the needs for seaweed products, public policy implications of mariculture, and the enumeration of the most favorable seaweed cultivation industries in southern California.

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The Culture of the Mussel, *Perna perna*, and the Mangrove Oyster, *Crassostrea rhizophorae*, in Venezuela

ENRIQUE F. MANDELLI and AMADO ACUÑA C.

Figure 1.—Location and number of rafts for mariculture operations in eastern Venezuela.

ABSTRACT — The coastal areas of eastern Venezuela offer excellent opportunities for the culturing of mollusks, as suitable unpolluted growing areas with all the ecological requirements are available. Culture of the mangrove oyster, Crassostrea rhizophorae, *and the mussel,* Perna perna, *in Venezuela was started in the early 1960's, using the successful Spanish raft techniques. In spite of initial promising results, oyster and mussel culture in this Caribbean region is now practiced on a small scale. Rapid growth and high yields are the characteristics of these cultures. Projected yields of 200-300 tons/ha/yr for* C. rhizophorae *and 1,000-1,200 tons/ha/yr for* P. perna *were estimated. Studies on* P. perna *growth in relation to environmental parameters are presented and culture guidelines recommended. The future development of the industry is also discussed.*

INTRODUCTION

In the coastal regions of eastern Venezuela the mangrove oyster, *Crassostrea rhizophorae* Guilding, and the mussel, *Perna perna* Linnaeus, are widely distributed in protected mangrove areas and rocky shores, respectively. These mollusk fisheries are relatively small (Food and Agriculture Organization of the United Nations, 1972) and mainly based on the harvesting of natural stocks which in the case of the oysters is done in a wasteful and destructive manner.

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The region offers the necessary prerequisites for mariculture of these mollusks. Initial attempts were begun in the early 1960's. Carvajal (1962) and Velez (1968) reported on the experimental culture of *C. rhizophorae*. Andrew (1962), on the other hand, described the encouraging results obtained in the culture of the mussel *P. perna*, as compared to *Mytilus edulis* culture in Spain. However, in spite of initial promising results, after a decade the culture of mollusks in eastern Venezuela represents a small-scale operation of unfulfilled potential.

This paper reviews the current commercial and experimental efforts to further develop the mariculture of *C. rhizophorae* and *P. perna* in eastern Venezuela.

CULTURE AREAS

Suitable growing areas for mollusks in eastern Venezuela are found within the inshore regions of the southeastern Caribbean Sea. This area is characterized by intense upwelling along the coast and in the Gulf of Cariaco. The northern and southern shores of the gulf are dotted with protected inlets, some of them fringed with dense mangroves (Fig. 1). To the west in the Caribbean Sea there are several potential areas for mariculture, such as Mochima Bay and the Gulf of Santa Fe. To the north, Margarita Island offers excellent ecological conditions for oyster culture. For example, La Restinga Lagoon is a well protected area with many inlets lined with dense mangroves, their roots covered with oysters. Along the northern shores of Sucre State between Manzanillo and Morro del Puerto Santo lie extensive mussel growing areas which provide the seed for current mussel mariculture. Mollusk culture operations are localized now in the Gulf of Cariaco and in La Restinga Lagoon on Margarita Island.

CULTURE TECHNIQUES

The culture of mollusks off the bottom by using Spanish raft techniques has been very successful in Venezuela. Both *C. rhizophorae* and *P. perna* are reared utilizing those techniques, though slightly modified. The suspended or floating culture practice offers several advantages. It can be adapted to shallow waters independently of the type of bottom, and the cultured organisms are protected from benthic predators. Moreover, the water column within the euphotic zone can be conveniently utilized.

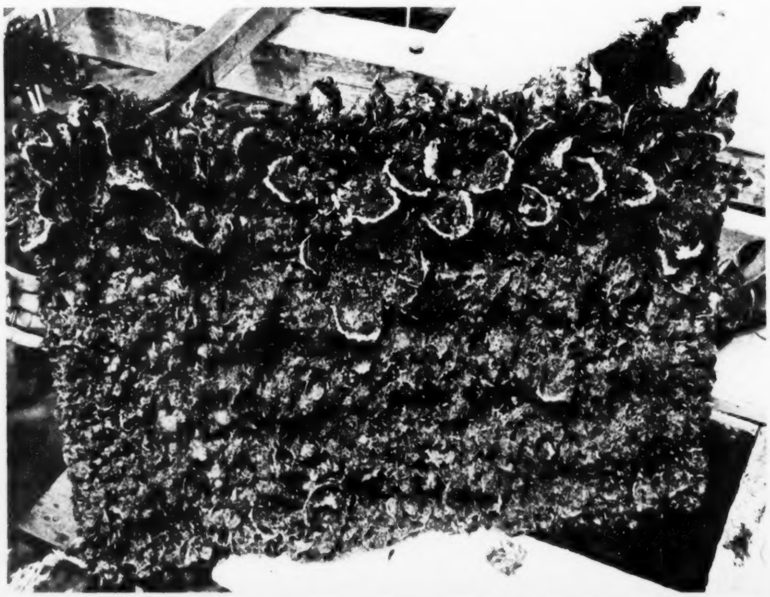
Figure 2.—*C. rhizophorae* raft in La Restinga Lagoon, Margarita Island.

The culture of mangrove oysters in La Restinga Lagoon is conducted using wooden rafts of varying sizes from 8 to 12 m² (Fig. 2). The abundance of larvae in the lagoon waters insures a constant source of seed. Larvae collectors made of asbestos and cement sheets, 40 × 80 cm, are suspended from rafts below the water surface. The number of larvae collectors varies from 170 for small rafts to 260 for large ones. After setting, the larvae are allowed to grow to about 2.5 cm in length, and only 200-300 are kept on each collector. From this point on, the juvenile oysters are treated at monthly intervals with a lime suspension for 15 min to eliminate space and food competitors. This treatment does not affect the oysters, which reach marketable size in about 6 mo (Fig. 3). The harvested oysters exhibit thin shells as compared with specimens of *C. virginica* of the same size. Rafts in La Restinga Lagoon are now producing between 20 and 30 kg of oysters per collector. Based on these yields, a production of 200-300 metric tons/ha/yr can be projected, considering one crop per year. These figures are from four to five times as great as those reported for Japanese cultures with yields of 58 tons/ha/yr (Ryther and Bardach, 1968).

The culture of mussels as practiced in Venezuela resembles operations in the highly productive Galician bays of northern Spain. As stated previously, the mariculture of *P. perna* is mainly localized in the Gulf of Cariaco near Cumaná. Initial experimental cultures were established in the Caribbean Sea along the rocky shores near Carúpano. However, a combination of adverse factors conspired against the success of the industry in that region. Rafts were damaged by rough seas during the windy season, and heavy crop loses were produced by red tide outbreaks.

The mariculture of *P. perna* in the Gulf of Cariaco involves the following steps: Juvenile mussels, 2.5-3.5 cm in length, are attached to polypropylene, to sisal ropes, or to wooden sticks of guatacaro (*Beureria cumanensis*) with rayon netting being used to hold them in place until natural

Figure 3.—Oyster cultch at harvesting time.



attachment occurs. Of the three systems in use, the one employing guatacaro sticks is the most economical since this wood is impervious to attack by marine boring organisms. The sticks or ropes, ranging from 4.5 to 6.5 m in length, are hung from rafts varying from 7 × 5 m to 26 × 16 m in size (Fig. 4). Smaller rafts holding 200-300 ropes are easier to operate and maintain. When mussels reach a size of about 4-5 cm in length, they are redistributed on additional ropes in order to prevent losses due to detachment and in order to minimize overcrowding, thereby stimulating growth. The harvesting of the mussels takes place after an 8- to 10-mo period. The yields vary according to the length of the ropes from 50 to 80 kg per rope, with a 10 × 10-m raft producing an average of from 10 to 20 metric tons of mussels. A projected yield of from 1,000 to 1,500 tons/ha/yr has been estimated. These projected yields are from three to five times as high as those reported by Spanish operations (Ryther and Bardach, 1968).

ENVIRONMENTAL FACTORS AND MUSSEL CULTURE

During the 1972-73 season a study was carried out on the growth of *P. perna* mussels from an experimental raft in close relation with some environmental parameters. The fluctuating physiocochemical and biochemical properties of the seawater at the site of the culture were tentatively used to formulate general guidelines for mussel culture in the Gulf of Cariaco. The gulf is a nearly isohaline body of water; thus salinity at the experimental site ranged from 36.47 to 36.78 ‰ during the experimental period. The seawater temperature for the same period varied from 24.2° to 28.2°C at the surface and from 21.6° to 27.7°C at the depth of the rope length (6.5 m). Upwelling periods in the gulf were clearly evidenced by the temperature, oxygen, and nutrient distribution data.

In terms of primary organic production the Gulf of Cariaco can be described as an upwelling province (Ryther, 1969). In the studied area, primary organic production ranged from 0.1 to 2.34 g C/m^2/day, representing a potential yield of 235 g C/m^2/yr for a water column 10 m deep. Two different production seasons were distinguished. From January throughout August, upwelling in the gulf maintained high levels of primary organic production. During the September-December period, however, production levels declined (Fig. 5). Production during both seasons was related to the prevailing winds in the area. The standing crop was dominated by diatoms in the highly productive period and by μ-flagellates the rest of the year, while dinoflagellates predominated in the transition period.

The experimental mussel culture was started in August 1972. The shell length of the seed used had a modal class of 35-38 mm. Juvenile mussels were attached to 300 sisal ropes at a density of about 3,000 per rope. Monthly growth rates were determined by sampling from nine ropes distributed along and across the raft. The procedure consisted of sampling 60 mussels per rope at three different depths with a total sample of 540 specimens collected each month. In Figure 6 are shown the monthly mode of shell growth, body weight gains, and condition index. During the experimental period, rapid growth of the mussels coincided with the end of the 1972 upwelling season, followed by minimum growth from October to December, 1972. The latter period showed low levels of primary organic production. Growth picked up in January 1973 after the onset of the new upwelling season and was maintained at a constant level until harvesting time in April 1973. The pattern of *P. perna* growth was similar to that reported by Carvajal (1969) and Velez and Martinez (1967) working with mussels in their natural habitat.

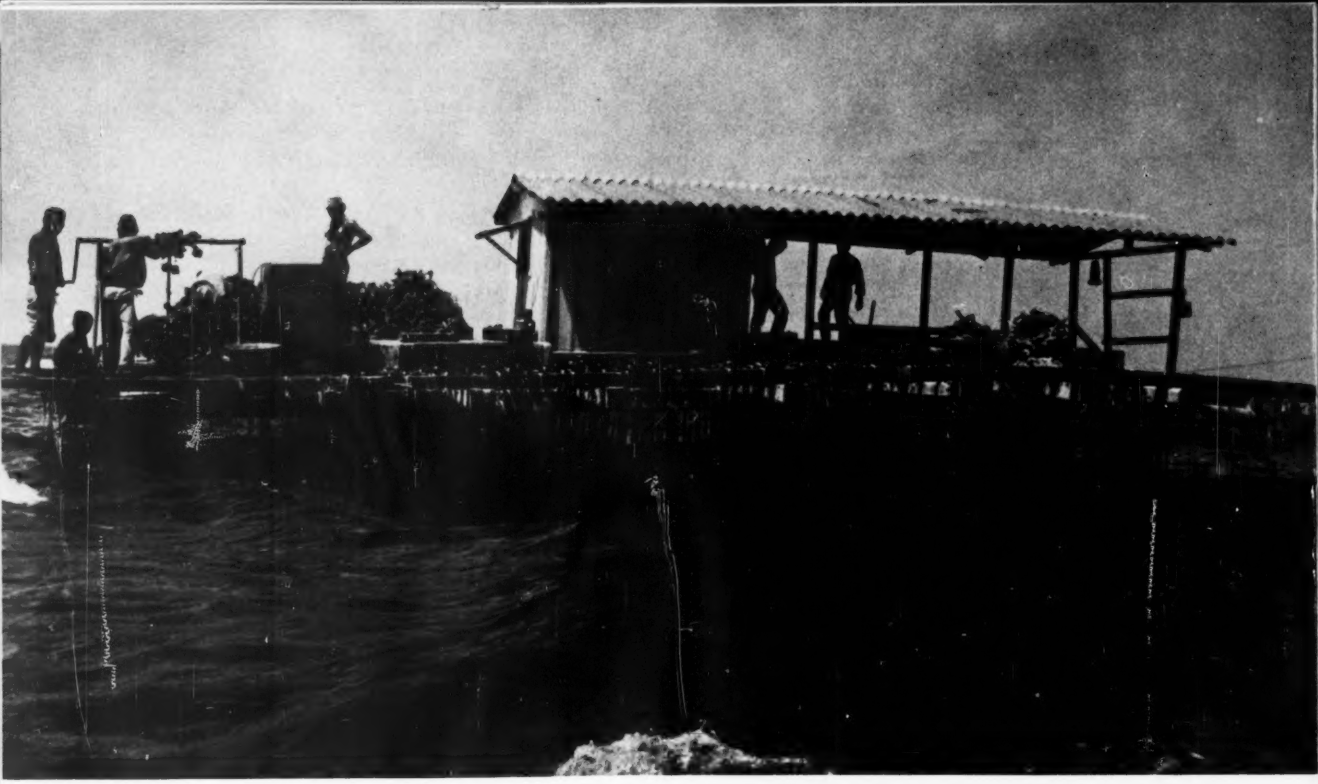
Regarding the spawning of this species, Carvajal's work offers evidence that the process takes place within the upwelling period. Spawning was apparently triggered by a sharp seawater temperature drop of 3-4°C. During the present study, spawning of the mussels in the experimental raft was not noticed. A commercial operation in the same general area, however, reported *P. perna* spawning in the June-July period (R. Martinez, pers. commun.).

Red tide outbreaks, which regularly occur in the Gulf of Cariaco, are a constant threat to the successful farming of mussels. To cite a specific case, in August 1972 a red tide patch developed in a localized area of the gulf and destroyed the entire mussel crop of six commercial rafts. Apparently there was a concentration of dinoflagellates in the bay followed by a windless period. It was not determined whether mussel mortality occurred due to the toxicity of the phytoplankter or by oxygen depletion when the standing crop decayed. At the site of the experimental culture on the same occasion we found the standing phytoplankton crop dominated by dinoflagellates not reaching red tide density. A similar type of phytoplankton distribution in the Gulf of Cariaco was determined in previous years (E. Reyes, ms. in prep.).

Considering the limitations of the accumulated information, the following recommendations are proposed to minimize adverse environmental conditions: First, the April-May period is a propitious time to start *P. perna* cultures. Three factors support this rationale—good, healthy seed is available, transplant of juvenile mussels will take place during the high productivity season, and the mussels will reach the low productivity period in good physiological condition even if spawning occurs by June or July. Second, mussels should be harvested between March and April of the following year after the onset of the upwelling season.

FUTURE OUTLOOK

It must be understood that current mollusk culture in eastern Venezuela cannot be considered true marine farming. Juvenile mussels are removed from their natural habitat and placed in favorable environments until they reach marketable size. Wild oyster larvae, on the other hand, are allowed to set in man-made cultch materials, and are reared under partially controlled conditions. In both cases man's aim has been to improve natural growing conditions by suppressing overcrowding and encouraging the rapid growth of the mollusks.



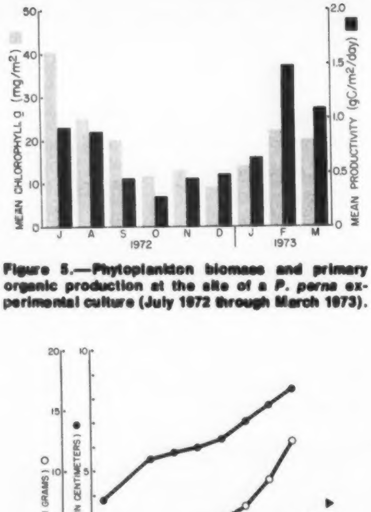


Figure 5.—Phytoplankton biomass and primary organic production at the site of a *P. perna* experimental culture (July 1972 through March 1973).

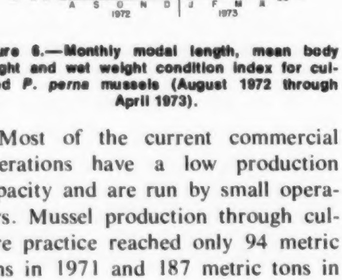


Figure 6.—Monthly modal length, mean body weight and wet weight condition index for cultured *P. perna* mussels (August 1972 through April 1973).

Most of the current commercial operations have a low production capacity and are run by small operators. Mussel production through culture practice reached only 94 metric tons in 1971 and 187 metric tons in 1972. So far this production has been absorbed by internal markets and has yielded reasonable profits. Further expansion of the industry can only be based on a dependable source of seed. In this regard, unregulated exploitation of *P. perna* banks is bound to limit future culture demands. Consequently, hatchery operations or the installation of larvae collecting rafts will be necessary. In either case, higher capital investment and operational costs will possibly curtail development. Cultures of *C. rhizophorae*, apparently freed from seed limitations, present other problems. The rapid growth of this oyster under controlled conditions produces specimens of marketable size but characterized by very thin and brittle shells needing careful handling. Further study is required to solve these and other problems. Thus, research priorities should include improvement of culturing techniques, controlled production of seed and even hybridization (Menzel, 1971). From a commercial standpoint it is uncertain to what extent *C. rhizophorae* and *P. perna* can compete with other, more valuable, species. In the ultimate analysis the expansion of both internal and external markets for these species will be the determining factor in the future development of this industry.

Figure 4.—*P. perna* raft in the Gulf of Cariaco area.

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MFR PAPER 1113

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Culture of the Bay Scallop, *Argopecten irradians*, in Virginia

MICHAEL CASTAGNA

INTRODUCTION

In recent years there has been an increased interest in the development of marine aquaculture or mariculture. Techniques for growing many traditional species, such as oysters and quahogs, have been developed, and considerable effort has also been made to test the feasibility of culturing new, less traditional species (Loosanoff and Davis, 1963; Iversen, 1968; McNeil, 1970; Price and Maurer, 1971; and Milne, 1972). This paper reviews the natural history of the bay scallop, *Argopecten irradaians* Lamarck, and presents a review of the Virginia Institute of Marine Science's (VIMS) continuing research on this species which began in 1968.

The bay scallop has several characteristics well suited for mariculture. It is fast growing, easy to condition and spawn, and is relatively hardy throughout all life history stages. Most important, it has a good market demand and commands high prices. Many species are biologically amenable to mariculture, but economics dictate the use of gourmet species which command high prices to defray high costs of culture.

Only adductor muscles of scallops are utilized. Yields vary, but approximately 1-1¼ bu of scallops produces 1 gal (9 lb) of adductor muscle. The price of shucked scallops rose to $38 per gal (for adductor muscles) in 1973, or over $4.20 per lb, certainly qualifying scallops as a gourmet food.

Utilization of shell and viscera would not significantly change the price or the demand. A mechanical

Bay scallops (*Argopecten irradians*), top photo, grew from 16 to 57 mm in size in pen in Assateague Channel from 9 July to 24 November 1970. Shucked, lower photo, 247 of these scallops yielded approximately 1 qt adductor muscle.

Scallop, showing developing gonad.

shucking and eviscerating machine developed for the calico scallop fishery along the southeast coast of the United States could be used on bay scallops (Webb and Thomas, 1971). This would markedly reduce manpower and cost problems associated with hand shucking.

Bay scallops retain the ability to swim at all sizes, making it necessary to confine them in suitable enclosures. Although this necessity increases expenses, it is partially compensated by reducing the cost of harvesting expenses.

NATURAL HISTORY

The natural history of the species has been described by Belding (1910), Wells (1927), Gutsell (1930), Loosanoff and Davis (1963), Sastry (1965), and Castagna and Duggan (1971). Bay scallops in the mid-Atlantic area spawn from mid-April through early September (Chanley and Andrews, 1971). Spawning in New England occurs when water temperatures reach 22-26°C (Belding, 1910). Although the scallops are hermaphroditic, self-fertilization is uncommon in nature (Belding, 1910; Gutsell, 1930). They usually release sperm first, followed by eggs (Loosanoff and Davis, 1963), which encourages cross-fertilization. Fertilized eggs develop into straight-hinge veligers in a few hours, and the larvae are planktonic for about 5-8 days. Longer larval periods are common when environmental conditions are less than optimum. The total length of the straight-hinge stage ranges from 85 μ minimum to 140 μ maximum (Chanley and Andrews, 1971).

Juveniles attach by byssal threads to eelgrass or other epibenthic support. They usually maintain attachment until 20-30 mm size is reached, after which most scallops drop to the bottom. Marine plants or other suitable cover is quite important to scallops. Small scallops (under 10 mm) do not survive well when exposed to silt. By attaching to the leaves or stems of submerged plants, they grow large enough to survive the more rigorous existence and greater exposure to silt on the bottom. Further, grass beds reduce current velocities. Work by Kirby-Smith (1972) indicates that scallops grow faster in slow currents. Maximum growth rates were achieved in 1-5 cm/sec, and a flow volume of 4 liters/hr/scallop the slowest current velocities tested. Scallops apparently retain their ability to form byssal attachment throughout their lives, but are seldom found attached when fully grown. They are active swimmers at all sizes and apparently use this ability to avoid predators such as starfish and crabs. Davis and Marshall (1961), studying the filter feeding of bay scallops, found an abundance of benthic and tychpelagic diatoms in the stomachs. They considered this an indication that much of the food is microflora, detritus, bacteria, and organic matter that is common in the water immediately adjacent to the bottom.

The bay scallop has a relatively high pumping rate, probably correlated with its rapid rate of growth. The average rate for small scallops, 38-44 mm in length, was 3.26 liters/hr. The larger scallops, 64-65 mm in length, averaged 14.72 liters/hr, with a maximum rate of 24.4 liters/hr (Chipman and Hopkins, 1954).

The average lifespan is about 12-16 mo with a few individuals surviving to 18 mo and rarely even to 24 mo (Belding, 1910). The scallop, typical of animals with short life cycles, exhibits great fluctuations in abundance.

MATERIALS AND METHODS

The procedures used by VIMS scientists for conditioning and spawning scallops and handling larvae were similar to those used by Loosanoff and Davis (1963). Stocks of spawners were collected from the seaside of Eastern Shore and from North Carolina. Scallops were grown in pens and floats built of plastic screen stretched over wooden frames. Measurements of scallops were from hinge to lip.

Seawater used in the laboratory was pumped from an adjacent creek by cast-iron pumps. All pipes and containers were plastic or glass. The seawater used for larvae and early juveniles was clarified by centrifugation in a Sharples[1] clarifier, Type AS-14, or a Westfalia separator, Model KDD 605. The average salinity for

[1]Reference to trade names does not imply endorsement of commercial products by the National Marine Fisheries Service, NOAA.

the experimental area was 29.5 ‰ with seasonal temperatures ranging from 3 to 28°C.

CONDITIONING FOR SPAWNING

The scallops were conditioned by placing them in aerated standing seawater at temperatures of from 18 to 22°C for 3-6 wk depending on food, temperatures, and the initial gonadal condition of the scallops (Castagna and Duggan, 1971). The conditioning was usually done on scallops taken from ambient-temperature seawater, which dropped as low as 3°C in winter. While held in standing water, the scallops were fed mixed algal cultures. The maturation of the gonads could be seen by holding the valves slightly open. The gonad is a triangular bulbish organ lying alongside the adductor muscle. When ripe, it is usually a red-orange color (often covered by a black epithelium). The testis comprises the white anterior border of the gonad (Castagna and Duggan, 1971).

SPAWNING

Spawning was accomplished by placing one or two adult scallops in a 1-liter Pyrex container filled with filtered seawater. A number of these containers were placed in a water table. By flooding the water table with hot or cold water, the scallops were subjected to temperature changes sufficient to induce spawning. Temperatures of 24-26°C induced maximum pumping activity. Temperatures were usually raised to 30°C for a few minutes and then dropped back to 24°C. Spawning usually took place at 28-26°C.

A sperm suspension (either stripped or spawned) was added to further stimulate scallops to spawn. Various chemical stimulants have been tested with little or no success. Both sex products are often released by the same scallop but usually not simultaneously.

After spawning the scallop was removed from the dish and the egg suspension was poured through a screen, to remove dirt and fecal material ejected by the spawner, into a calibrated container of filtered seawater. Eggs were counted by stirring the contents of the container and subsampling several 1-ml samples. An estimate of the number of eggs was made by averaging the counts and multiplying by the total volume.

Scallop in foreground (left) is spawning.

FERTILIZATION

Fertilization was initiated by adding approximately 6 ml of sperm suspension per liter of egg suspension. Fertilization was nearly 100 percent successful even when sperm and eggs from the same individual were used. The addition of too much sperm suspension can cause larval deformities, probably due to polyspermy.

DEVELOPMENT

Survival and development were usually enhanced by holding developing eggs above 20°C. Optimum temperature for development appeared to be 26-28°C. A minimum salinity of 22.5 ‰ was necessary for development to straight-hinge stage. At near-optimum temperature in 28-30 ‰ salinity, the blastula stage was reached in about 4 hr, trochophore stage in 8-12 hr, and straight-hinge stage in 16-24 hr. The embryonic stages preceding the straight-hinge stage were most vulnerable to environmental conditions, but with proper maintenance approximately 60 percent survival can be expected. Larvae from self-fertilized eggs usually appeared normal in the F_1 generation. Subsequent generations often had larval deformities and poor survival.

The larvae were grown in 60-liter plastic containers. Three times a week the water was siphoned from these containers through a fine nylon screen

to retain larvae. These were concentrated in calibrated containers of filtered seawater, subsampled, and counted by the same procedures previously described. Measurements of a small sample were taken using an ocular micrometer, and the general condition of the larvae was ascertained. The larvae were then redistributed to containers of clean filtered seawater containing food and, if necessary, antibiotics.

LARVAL DENSITY AND LARVAL ENVIRONMENT

Larval density, although not critical, influenced the success of a group of larvae. Since labor and space were often in short supply, it was tempting to crowd as many larvae into as few containers as possible. This practice increased the number of failures, perhaps by increasing chances of disease transmission or because of competition for food or space. To avoid these problems, cultures were started at maximum densities of 40 eggs per ml. As the larvae grew, their densities were reduced with each water change until densities of 5 per ml were reached when larvae were ready to set.

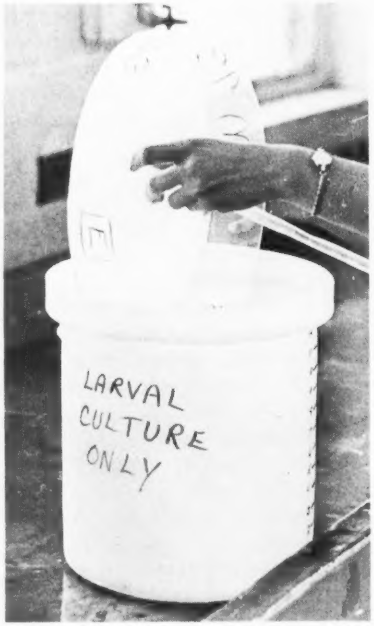
Aeration was not necessary for survival at the densities stated above. Gentle aeration enhanced growth rate and survival of late larval stages but made little or no difference in small or early larvae. Since scallop larvae set at a relatively small size, aeration was not used routinely.

FOOD

Several unicellular cultures of marine flagellates or diatoms were tried as larval food with varying degrees of success. In all trials, mixtures of two or more species worked better than one species. No artificial food mixture was found that gave comparable results.

Some successful species used were *Monochrysis lutheri*, *Isochrysis galbana*, *Phaeodactylum tricornutum*, *Dunaliella tertiolecta*, and *Nanochloris oculata*. Even though food was added, the water was changed periodically to cleanse cultures of metabolic wastes and dead larvae.

When raising large numbers of scallops (or any other cultured filter feeder), the logistics of growing sufficient unicellular algae become a serious problem. An excellent method of growing quantities of food is the solarium method, often referred to as the Glancy method. (Joseph Glancy, Sayville, N.Y. was the biologist responsible for introducing this method.) This method consists of clarifying and holding seawater in aerated vats in sunlight in a solarium or greenhouse. The stored water develops a bloom of diatoms and flagellates which can be used as food.



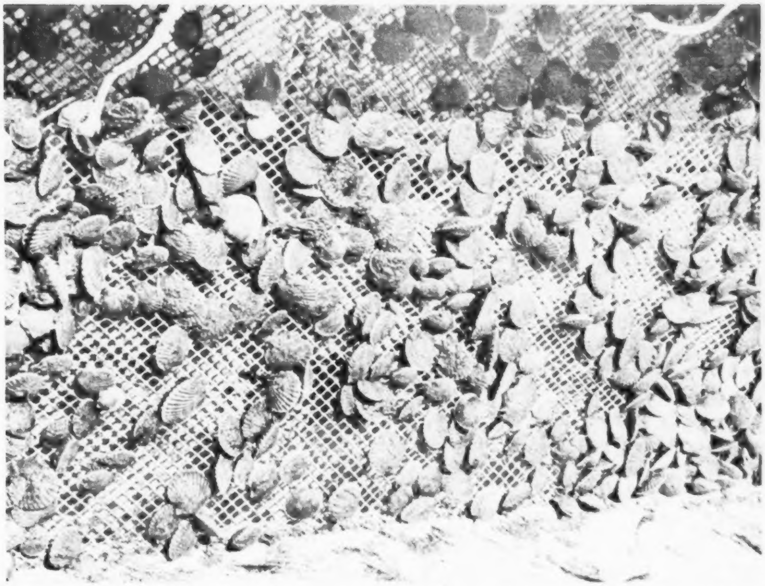
In top photo, a technician washes scallop larvae into container for counting and measuring. A technician grades scallop larvae in the lower photo.

The greenhouse method was used successfully at VIMS. Seawater was run through an AS-14 Sharples clarifier, which spins the water at 15,000 rpm in an 8-in diameter tube exerting 13,200 × *g*. Essentially a clarifier separates heavier particles by centrifugal force instead of gravity. The clarified seawater was then stored in 4 × 8 × 4-ft fiberglassed plywood tanks in a solarium and was continuously gently aerated. The clarified seawater retains small diatoms, flagellates, and protozoans. Heavier and larger forms, including zooplankters and diatoms with dense or heavy tests, are left on the wall of the clarifier tube. When stored in a solarium, the water temperature in the large aerated ranks rises, and the small diatoms and naked flagellates reproduce in a bloom that eventually colors the water. Seawater treated in this manner was referred to as cultured water and was used as a medium in which to grow larvae and early juvenile stages. No additional food was required. The cultured water was normally held 24 hr before use. This was sufficient time for a bloom to occur. If stored water was not used in 48 hr, it was usually discarded, since new cultured water resulted in faster growth and better survival of the larvae. Fertilization or inoculation was not necessary to attain dense blooms of useful food organisms.

Mixed wild algal cultures that grow in this system (Glancy method) were better foods than any combination of unicellular algae tested. Growth and survival were usually better than in larvae fed unicellular cultures.

LARVAL DISEASES, PREDATORS, AND COMPETITORS

Diseases, predators, and competitors were controlled by maintaining clean conditions. No physical, chemical, or prophylaxis treatment was used routinely except when water temperatures were over 28°C. Then, water was subjected to ultraviolet



Scallops in growing container.

light treatment. This treatment is reviewed by Loosanoff and Davis, (1963).

The most common disease problem was bacillary necrosis. This was treated with streptomycin (50 mg per liter) or with a wide spectrum antibiotic such as chloromycetin or polycillin. Care was taken in estimating dosage since antibiotics often caused the larvae to stop feeding for several days, and overdoses caused mortalities.

Arthropods often appeared in the larval cultures. These were controlled with tetraethyl pyrophosphate. Four drops in 60 liters of culture would usually kill all arthropods in less than an hour. Obviously this is a potent chemical and should not be used indiscriminately. Arthropods were also removed by screening. This method was preferred over chemical control.

Protozoans often appeared as a symptom of bacterial contamination. They were controlled by reducing the number of bacteria with an antibiotic.

As always, labor and space were considered as in a commercially-oriented culture practice. Therefore, it was usually more expedient to discard poor or sick cultures and start over rather than attempting treatment.

SETTING

Setting took place in 5-7 days, depending on food, temperature, and probably other environmental and genetic factors. The most obvious indication of spat stage was attachment by byssal threads to the culture container. The early juveniles have a well-developed foot with a heel-like byssal gland. The shell measures 175-200 μ at metamorphosis (Chanley and Andrews, 1971). This period, when the scallops were undergoing metamorphosis, was probably the most critical, and often heavy mortalities occurred.

Through early metamorphosis or setting, the scallops were kept in clarified water or in slowly flowing raw seawater. At this time vertical surfaces for attachment were presented to the setting scallops. These were panels of wood, mylar, or fiberglass that the juveniles fastened to by their byssus. Juveniles apparently preferred vertical surfaces and most were found clinging to the sides of the containers or the panels. As food requirements increased, flowing raw seawater was introduced. A screen of suitable size was placed at the overflow to retain scallops that were sucked into the overflow pipe while swimming. Juveniles were held in this manner until they reached 10-13 mm size, large enough to stay in ¼-in plastic screen.

When the juvenile scallops were moved into the field, they required confinement to prevent them from swimming away. A variety of enclosures were used. Floats anchored at the surface had severe fouling problems which reduced the flow of water. Additional problems of boat wakes and wave action, washing the scallops about in the floats and often causing a concentration in a corner with some loss due to smothering, were also encountered. Floats placed on the bottom had fewer problems but the scallops did not grow well.

The most successful growth and survival was in pens constructed of poles placed into the bottom with ½-in mesh plastic screen tacked around the outside of the poles. The pens were 10 ft square and 7 ft high. They were constructed in shallow subtidal areas.

Bay scallops grown in pens were brought to market size in 5-7 mo. Further, the adductor muscle was considerably larger than in scallops grown in floats. This may be due to

Juvenile scallops tagged and ready to be released.

the opportunity of scallops in pens to make vertical swimming excursions. The size of the adductor muscle is important since it is the only part of the scallop which is sold.

A series of tests were completed to assess the best depth to grow scallops. Little difference was found between depths if fouling, silting, and washing could be controlled. Experiments were also run to find the maximum optimum number of scallops per unit area that can survive and grow. Optimum growth and survival were found at 25 per sq ft of bottom area. However, the data suggest that 60-65 scallops per sq ft would be optimal economically, even though growth rates were less than optimum (Duggan, 1973).

PREDATORS

Although smothering is definitely the main cause of death, there are some serious predators. The rough oyster drill *Eupleura*, starfish, crabs (especially the blue crab, *Callinectes sapidus*) and various fish species are known predators of this species. No predator control methods were used in these experiments, but they should be considered in any commercial venture.

ACKNOWLEDGMENT

Grateful thanks are due to Nancy Lewis, Sharon Schneider, Mike Peirson, and Rick Karney for their assistance in carrying out these experiments. My special thanks to W. P. Duggan for his collaboration and help in much of this work and for carrying out most of the work on enclosures, densities, and depth experiments. I also wish to thank J. D. Andrews whose suggestions and review were greatly appreciated.

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MFR PAPER 1114

Crustacean Aquaculture in Middle America

HAROLD H. WEBBER

INTRODUCTION

This paper is designed to inform the reader regarding the technical and economic feasibility of establishing a profitable aquaculture venture in certain specific locations on the west coast of Central America.

The recommendations made here are predicated on the following basic premises:

1) The continuing paucity of high-value crustacean aquafoods in the expanding world markets demands that new sources of supply be developed.

2) An aquacultural production technology is maturing which will enable us to generate large volumes of shrimps at favorable cost.

3) The risks and rewards of a vertically integrated aquafood enterprise have been evaluated, and the business projections reveal an advantageous return on investment.

MARKETS

There exists a market for high-value crustacean aquafoods, including marine and freshwater shrimps, lobsters, and crabs, which is now unsatisfied and is likely to remain supply-constrained for the remainder of the century. This is a consequence in part of an increasing affluence in the highly developed industrial societies in the north temperate latitudes. This elevated economic status

increases purchasing power, allowing for an improved standard of living and a widened consumer acceptance of less conventional and more expensive foods. Concomitant with the increasing demand, the traditional shrimp trawling industry has just about exploited the known wild populations of shrimps and prawns of the world's oceans, and we are now approaching the maximum sustainable yield (Cleary, 1970) obtainable from the wild resource. Additional significant supplies, therefore, we propose, must come from controlled, farm-raised production.

Dependence on the hunting and gathering arts is subject to the natural vagaries in the fluctuation of wild populations, and thus the market for aquafoods is often disturbed by oversupply or undersupply. On the other hand, a deliberately cultured product line that is produced in accordance with a reliable measurement of demand, and supplied into the market place on a continuous and scheduled regimen, can capture a significant market percentage and growth. The opportunity to service the HRI (hotels, restaurants, and institutions) market with controlled portions in a large range of sizes and forms under strict quality control with precise delivery schedules can be most readily exploited by an aquafarming business such as we are proposing here. Most successful high-wealth generating food industries owe their short-term achievements to the end that essential human needs are served or human desires are gratified. In the long run, however, the economic success will be in large part a consequence of the provision of high-quality products with an assurance of continuity of supply. To accomplish this goal at profitable economic levels, a sustained high productivity must be realized which in turn will be the result of wise management of the natural resources from which the bioindustry generates the wealth.

Harold H. Webber is the president of Groton BioIndustries Development Company, P.O. Box 517, Groton, MA 01450. This paper was originally presented at the symposium Aquaculture in the Americas held at the Inter-American Scientific Meeting, "Science and Man in the Americas," jointly sponsored by the American Association for the Advancement of Science (AAAS) and Consejo Nacional de Ciencia y Tecnología (CONACYT), México 18, D.F., México, 20 June to 4 July 1973.

Let us, then, first examine the needs and desires for crustacean aquafoods as they were expressed in the markets of the world for the past decade or so, and also as we can project the demand into the near and distant future.

Of the 69 million metric ton total world fisheries catch in 1970, approximately 1.6 million tons were crustaceans (Food and Agriculture Organization of the United Nations, 1971a). Of the crustaceans harvested, over 52 percent entered into world commerce, whereas somewhat less than one-third of the fresh and frozen finfish were traded in world markets. The mean landed value per pound of crustaceans was approximately five times that of finfish (Food and Agriculture Organization of the United Nations, 1971b).

The world catch of crustaceans generally has not kept pace with demand over the last decade. The U.S. supply of northern lobsters and of crabs has actually declined over this period, and the supply of spiny lobsters has increased relatively little and is now at only 54 million lb. The U.S. landings of American lobsters have been relatively constant over the past few decades at approximately 30 million lb, but over the past decade imports have declined because of the limited catch and the competition for the supply. The supply of crabs in the U.S. market is also seriously constrained.

The commercial shrimp trawling industry has realized considerable growth in the past 2 decades, in large part as a consequence of an apparently insatiable market demand for crustacean aquafoods in the developed markets of Europe, North America, and Japan. This demand has supported and justified a continuing search for new, previously unexploited wild populations of shrimps and prawns in the world's oceans, as well as a commensurate effort to improve fishing efficiency by the design and development of improved detection methods and catching gear. However, the significant success in increasing the catch year after year, has not kept up with the market demand, and consequently the selling price for shrimp in the developed world has responded with mounting annual increases. In the United States, shrimp sold at $1.05 per lb at retail in 1960, whereas by 1972 the mean selling price was $1.87 per lb. The United States demand has increased at a rate of approximately 6 percent per year, far exceeding the rate of population growth, so that the per capita consumption has approximately doubled, from about 1 to 2 lb over the last decade, while at the same time price has also increased 6 percent. Roedel (1973) predicted that the U.S. shrimp business would be at $1 billion at retail in 1973. Over the same period, the native U.S. shrimping grounds have been unable to sustain commensurate production. Therefore, the supply has had to be supplemented by imports, which in 1972 were 52 percent of the 488 million lb supply (Anonymous, 1973).

Cleary (1970) has estimated that shrimp harvests will level off within this decade, and that U.S. demand will exceed the world supply by 1980 if we depend on the wild resource. At present the U.S. market alone accounts for 1.1 million lb of shrimp a day.

There has also been a considerable increase in competition for the world supply of shrimps and prawns over the past few years. The U.S. and Japan now account for half of the world consumption. The European Common Market which has a combined population higher than that of the United States is beginning to compete vigorously with the United States and Japan for the already limited world supply.

Nonetheless, as long as the high demand and selling price for shrimps and prawns continues to increase, there will be a strong economic motivation to develop a supplemental source to the trawler-caught stocks. A maricultural system for rearing these animals in large numbers may provide a mechanism to accomplish this end. By the application of sound

animal husbandry practices, we may expect to achieve an assurance for a reasonably constant year-round supply, thus freeing the market from the vicissitudes of a hunted resource.

Since a large portion of the world shrimp catch comes from tropical waters bordering on the shores of the developing countries of Latin America, Africa, and Asia, and the major markets are for the most part in the developed countries of the northern latitudes, an important contribution to a favorable foreign exchange balance is achieved by many developing countries in the American tropics.

CULTURE TECHNOLOGY

There exists new fundamental knowledge in aquatic biology, and an advanced comprehension of some of the interactions of the complex factors which contribute to successful high-intensity farm culture of penaeid (saline water) shrimps and macrobrachian (freshwater) shrimps. We at BioIndustries Development Company[1] have contributed to, and are in command of, this current aquatic animal husbandry technology and are now in a position to attempt to optimize the system in order to achieve a level of efficiency to ensure a profitable economic enterprise.

An essential component of the new technology is larviculture to produce seed shrimp for the stocking of nursery facilities. The staff of BioIndustries, led by Durbin C. Tabb, has made important contributions to the development of this technology (Tabb, Yang, Hirono, and Heinen, 1972). A hatchery facility is required in which gravid (egg-bearing) females, procured from the commercial trawler fleet, are induced to spawn in large tanks. The resulting larvae are reared through the several stages of larval growth on appropriate feeds that are cultured for the purpose, and environmental conditions such as water temperature, salinity, and light are critically managed to ensure high survival and growth rates.

The grow-out technique that we have developed involves a two-step process. First, postlarval shrimps are stocked in small nursery pools or tanks and grown in very high population densities. Intensive management practices provide that water quality and other environmental conditions in the nursery are maintained as close to optimum as is practicable. Since each individual is extremely small at this life stage, the ratio of biomass per unit water volume is quite low, and therefore the problems of sustaining a high-quality cultural environment are thereby reduced. The young, when fed appropriately, can be grown to about 2-3 g each in 45-60 days at the high stocking density maintained in the nursery, but at that size they must be thinned out. They are then stocked at the rate of at least 20,000 per acre into the final 10-acre grow-out ponds, and fed natural feed and supplemental formulated rations until they have reached market size in about 90 days.

Stocking density, feeding rates, predator and competitor control, disease and parasite management, and pond engineering and management have all been studied intensively by our staff as critical components of a total system. We have satisfactory empirical evidence that these matters are now amenable to practicable management control (Webber, 1970).

Various harvesting methods have also been studied in grow-out facilities of economic scale, and with mature populations of economic size. We are confident now that harvesting techniques or costs will not be a limiting economic factor, although we can anticipate further improvements and reduced costs over our present proven procedures.

SITING THE ENTERPRISE

The many considerations which impose themselves on the selection process for locating an aquaculture venture are discussed generically by Webber (1972). In the specific case of a shrimp aquafarming venture being considered here, certain priorities of a specialized consideration have been assigned to the criteria for site selection. The judgment employed in weighing the criteria is a consequence of considerable experience and understanding gained from our continuing effort to establish an economic shrimp culture system in Central America.

Based upon the high visibility reflected in demand of the penaeid shrimps in world commerce, and the consequent certainty of the acceptance of this produce in the major marketplaces of the world, we have placed our emphasis in this venture study on the marine shrimp species of the genus *Penaeus*. This emphasis then dictates that the aquafarm site must be supplied with an abundance of high quality saline water. Thus we are confined to a quest for a coastal zone site.

On the other hand, a rapidly growing technology has now matured for the culture of freshwater shrimps of the genus *Macrobrachium* (Fujimura and Okamoto, 1970). BioIndustries Development Company has been contributing for several years to this development and has grown out *Macrobrachium* in Honduras. This aquafood has not yet achieved significance in world trade, and is not yet caught from the wild or produced in culture in large quantities. However, macrobrachian shrimps are highly prized and command high prices as specialty aquafoods and, when available, compete favorably in the market with the penaeids.

Because of the advanced state of the culture technology, market acceptability, and the apparent favorable economics, we shall incorporate a consideration of *Macrobrachium* culture into this investigation, although in the economy of time we shall consider it secondarily to the penaeid culture venture. Nonetheless, the site selection demands of a macrobrachian aquafarm have been incorporated into our assignment of priorities of criteria for a penaeid aquafarm.

There are certain economies that can be realized from a dual farming venture. For example: whereas the penaeid grow-out facilities must contain saline waters and the macrobrachian culture ponds require freshwater, the same hatchery facilities can be utilized for both, since the macrobrachian spawning and larviculture requires a brackish water environment. Salinity control in the hatchery must be precise and thus provides for a range of levels. Thus, a hatchery located on an estuary that is subject to high tidal flushing, but

[1]Mention of trade names does not imply commercial endorsement by the National Marine Fisheries Service, NOAA.

is somewhat inland from the seacoast where good road access, power, labor, etc. may be actually more readily available than if the hatchery were located on the seashore itself, could serve both upstream macrobrachian ponds and penaeid ponds located on the tidal flats.

A single feed formulating and mixing facility may well serve both systems of culture. Common feed storage and bulk transport could be used. Similarly, one processing plant could handle the production of both farm complexes on essentially the same equipment and with the same labor. Finally, having various product forms from both genera of shrimps could extend the product line and thus provide greater leverage in the markets to serve a more comprehensive market strategy.

Penaeid shrimps as a genus are generally found in warm waters. They are frequently captured in the temperate zone; however, this latter catch is limited to the few summer months when water temperatures exceed 20° C. Even the U.S. coast of the Gulf of Mexico, with its vast shrimp populations, has winter water temperatures that are too low for shore-based culture systems. The species of shrimp that we have found most promising for culture are found in commercial quantities only in tropical waters. Mazatlán, Mexico, a major shrimp port on the Pacific Coast which is almost on the Tropic of Cancer, is about the northern limit of the Pacific white shrimp species upon which we have elected to concentrate our efforts. We view the Tropic of Cancer as the northern limit within which we can operate a shrimp aquafarm. The Tropic of Capricorn defines the southern limit within which economic shrimp aquafarming may be practiced. Another way to characterize this water temperature dependence is by the temperature range within which the tropical species of shrimps grow well. We can, for our present purposes, set the limits at 24-32°C, seeking the 28°C optimum mean temperature.

Photoperiod is an additional significant characteristic of the tropical environment which we feel has a strong influence on the physiology and on the behavior of tropical penaeids. Length of day can materially influence the reproductive cycle, and since this matter is of major concern to us, we feel that if we are to grow tropical species they can best be managed within the tropical zone.

Light intensity and quality, as well as the total solar energy impingement, are extremely important influences on primary productivity. In the environments which we expect to manage, these factors are most crucial ecological contributors to the natural nutritional support of high density populations, and they will appreciably reduce production costs by reducing the reliance on formulated rations that may have to be purchased. Here again the narrow annual range of fluctuation of the essential environmental parameters in the tropical latitudes provides the greater opportunity to realize other economic benefits, such as continuous year-round production by making wise use of these resources.

Therefore, an important high-priority site selection criterion, which we feel has to be satisfied before others are considered, is to locate the shrimp aquafarm in tropical waters. The tropical environments suitable for culture of the selected species and nearest to the North American markets may be found on the west coast of Central America.

The Pacific Coast of Central America is exposed to considerable tidal fluctuation (from as much as 16 feet in Panama to 9 feet in Puntarenas in Costa Rica, and about the same in La Unión, El Salvador). Furthermore, in the deep embayments of the west coast of Central America, Panama, Colombia, and Ecuador (a region which we shall identify as "Middle America"), which form such bodies as Golfo Dulce, Golfo Nicoya, Golfo Fonseca, Bahía de Jiquilisco, etc., there are shallow-water shores which in combination with the high tides result in wide intertidal zones. These coastal tide flats are generally occupied by mangroves. These regions make very attractive culture sites. Flowing through these wide intertidal mangrove swamps are many streams and rivers carrying the freshwater runoffs from the very high rainfall that occurs in the high mountain ranges close to the sea. These estuaries (esteros) provide elegant manageable waters from which the appropriate salinities can be selected.

We determined that the indigenous Caribbean species, which are identical or similar to Gulf of Mexico forms studied intensively in U.S. laboratories, are slower growing than certain Pacific Coast species of white shrimp, such as *Penaeus occidentalis*, *P. stylirostris*, and *P. vannamei*.

Whereas we now place a great deal of importance on the species of shrimp to be cultured, it is not sufficient alone to have identified them and learned how to rear them. It is also important from a business point of view to have ready access to large stocks of these animals from the wild, since we are not yet able to sustain lines of brood stocks in captivity. Until we have command over the reproductive cycle of penaeids, and can induce gametogenesis (production of eggs and sperm) at will, we must procure from the wild populations, gravid (egg-bearing females who are carrying spermatophores, or attached packets of sperm) shrimp, bring them into an appropriate hatchery facility, and induce them to spawn. The technical and cost efficiency of this stage of the culture system is in large part influenced by proximity of the hatchery to the port of a large shrimp fishing fleet, as well as the cooperation of the trawler captains.

This requirement is more readily satisfied on the Pacific Coast where the largest Central American, Panamanian, Colombian, and Ecuadorian commercial shrimp fisheries exist. The ports and processing plants that serve these shrimp trawling fleets are generally located where other resources are also available.

On the other hand, the consideration of access to wild gravid females imposes no constraint on site selection for a macrobrachian aquafarm. This genus of crustacean reproduces readily in captivity, and therefore can be reared wherever appropriate freshwater supplies are available, and where edaphic, climatologic, and the complex of economic factors can be satisfied. Consequently, we are justified in placing the macrobrachian aquafarm site selection secondary to that of the penaeid farm. Within a

wide region along the Pacific Coast of Central America there is very high rainfall, and therefore an abundance of fresh water may be available within a practical distance of a selected penaeid farm site. The need for good quality fresh water for macrobrachian culture is such that the heavy use of pesticides (on a cotton farm for instance) might exclude the possibility of freshwater shrimp culture in the area. The presence of biocides in any culture waters, from whatever sources, of course, must be avoided.

Having thus generically defined the geographical, climatological, meteorological, and oceanological criteria as being best satisfied in a tropical environment, and having also imposed on the selection process certain more specific parameters such as the requirement for high tidal amplitudes in conjunction with extensive intertidal hectarage, as well as the requirement for access to gravid penaeid females of the appropriate species, we then are confined in our search for a site to the Pacific Coasts of Central America, Panama, Colombia, and Ecuador. At this time we are not considering Mexico because of the legal constraints imposed by limiting shrimp exploitation to cooperatives only.

Finding satisfactory ecological conditions, although extremely important, will not alone insure the success of the venture. Among the many other requirements which must be satisfied is the economics of bringing the product to market. Since we are contemplating a large-volume production of a frozen-food product, and we anticipate shipping the product primarily to North American, Japanese, and European markets, it is most likely that we will utilize modern refrigerated containerization techniques for oceangoing freight for shipping most of the production. We can anticipate that only small quantities of the fresh product will be airfreighted to distant markets or sold into domestic markets.

Since the ports serving the major shrimp markets in the United States are on the Gulf Coast and on the eastern seaboard and the routes to the European markets are Atlantic, a large portion of our ocean freight may pass through the Panama Canal. Therefore, on the basis of oceangoing transportation alone, proximity to the Panama Canal is an additional site-selection criterion which we should consider. There is, on the other hand, a growing practice of trucking the frozen, packaged product overland to Caribbean ports such as Puerto Barrios in Guatemala, or Limón in Costa Rica (Gross, 1973). We recognize that the Japanese and other developed Asian markets are equally accessible from any of the Pacific Coast countries of Middle America. While Ecuador, Colombia, and Panama are all significant exporters of penaeid shrimps to the U.S. market and have very attractive, ecologically favorable sites, we have elected to relegate these countries to a secondary consideration at this time either because we find their political and social climates less satisfactory, or because we are less familiar with them than we are with certain Central American countries.

Although BioIndustries Development Company has had reasonable experience, and still has an interest in an aquacultural business in Honduras, we find the political and economic risks too uncertain to justify investment at this time. Furthermore, Honduras has a very limited Pacific Coast shoreline on the Golfo Fonseca and no significant Honduran-based Pacific Coast shrimp fishery, and consequently no port facilities there. Thus, there would be very limited access to gravid females from commercial trawler fleets. This leaves the countries of Costa Rica and El Salvador as the acceptable candidates.

Both El Salvador and Costa Rica are in reasonably secure economic positions, although such matters fluctuate. Both countries are politically stable at this time. Costa Rica especially has a long history of democratic government, and has a large middle class with considerable purchasing power; Costa Ricans have the largest per capita income in Central America.

This relative affluence is reflected in the higher labor costs in Costa Rica, relative to other countries of Central America, but it is generally held widely that labor productivity there more than compensates for the slightly increased costs. The Costa Rican Investors Guide (Anonymous, 1972) quotes minimum wages that are favorable to a labor-intensive business.

In El Salvador, where labor is said to be very easily trainable and highly productive, some typical labor rates reported by Insafi (Instituto Salvodorena de Fomento Industrial) indicate that unskilled labor, as well as the skilled workers which we would employ, are paid at rates that will not burden a business. Other considerations such as investment incentives are very similar, and there is no important difference between the two countries. We have found that the Central American Bank for Economic Integration which is the development bank that fosters Central American Common Market growth, would look favorably on an aquaculture venture in Costa Rica and/or El Salvador.

Therefore, our site-selection field study may be limited to the Pacific Coasts of Costa Rica and El Salvador, and generally should be confined to what we judge to be an appropriate radius of the major shrimp port in each country. In El Salvador, we may investigate the mangrove covered intertidal zone around the port of El Triumfo where some 80 shrimp trawlers are based and regularly bring their catch to be processed and shipped. In Costa Rica the region around the port of Puntarenas provides the most attractive possibilities.

BUSINESS PLAN

The plan presented below is predicated on the premises noted at the outset of this presentation:

1) that there exist unsatisfied, receptive markets for the high-value products(s) that we propose to produce;

2) that the culture technology is sufficiently advanced to achieve high productivity, and that we have the knowledge and experience to apply this technology so as to achieve large-volume, low-cost production; and

3) that we have become aware, through empirical as well as theoretical evidence, of the essential components of a business system, including the imperative criteria for site selection, hatchery and nursery management, growout, harvesting and transport, processing a variety of acceptable product forms,

marketing into HRI and consumer outlets, and finance and agribusiness management.

An integration of the above-noted body of knowledge into the following business plan considers the known and calculable risks and presents the expected rewards. A consideration of the risks to aquaculture ventures has been presented by Webber (1973).

We shall here state, in reasonably conservative terms, our firm convictions based on experience and our reasonably assured expectations based on calculations, assumptions, and extrapolations. We intend to identify the bases of both classes of conclusions.

For the purpose of a venture analysis we shall concentrate our effort on the study of a Costa Rican site. This decision does not exclude El Salvador sites as potential locations for performing aquaculture businesses. We have elected to confine our investigation to the coastal regions within reasonable access to the port of Puntarenas, Costa Rica on the Gulf of Nicoya.

We have also chosen to confine our attention to the design of a business plan for the culture of marine shrimps of the genus *Penaeus*. This again does not mean that we do not hold in high regard the potential for freshwater shrimp culture business based on the genus *Macrobrachium*, but in the economy of our attention, time, and investment, we feel that it would be unwise to consider both genera simultaneously. We are, however, enthusiastic about a sequential approach which will bring a *Macrobrachium* venture into being soon after the *Penaeus* business has moved through its start-up phase.

We recognize that there is considerable commonality between the requirements for each, and we therefore have recognized the potential for the addition of a second genus. This consideration has influenced our restriction of the site selection to the Puntarenas region where upland freshwater and land resources appear to be favorable for macrobrachian culture. Such a culture can be integrated with the feed, harvesting, processing, and marketing sectors of the penaeid aquafarming business. In fact, it was because the fresh waters of the El Salvador site on the Bay of Jiquilisco are likely to be contaminated with pesticides that this region is relegated to a secondary choice.

The broad fringe of the extensive mangrove zone has several sites accessible by road and within easy communication with the port and other advantages of Puntarenas. The landward edge of the mangrove fringe, which is under government jurisdiction, can be leased under satisfactory terms of time and cost. The depth of the mangrove peat in this region has been observed to be in some cases from 3 to 4 feet, and it is underlain with heavy blue clay. These edaphic conditions in association with low labor costs of the region suggest that the cost of construction of pond levees will be low, and therefore we have estimated $350 per acre as the capital requirement for the construction of grow-out facilities. This figure includes sluiceway, gates, harvest sump, and drainage canals.

Although we present this venture plan with a high level of confidence in its potential success, and with high levels of assurance that our assumptions are reasonable and wise, we advocate a pilot operation as the initial phase of a development. We emphasize this recommendation because it has been the experience of most agribusiness that technology transfer cannot be made readily from one ecological site to another without considerable adaptation of those components of the system which are site sensitive. The effects of water qualities, meteorological variables, and other environmental influences on natural productivity, as well as the social, political, and cultural variables that influence the way business can be conducted in a given environment, can best be determined and understood empirically.

We therefore recommend that a pilot production farm, plus the supporting facilities, be operated for a sufficient period of time to prove (test) the technical and economic aspects of a proposed plan. We can anticipate that a pilot or start-up period may require 18-24 mo. It should be recognized that this first-phase period is not a research and development effort, but is primarily a trial of an existing technology being applied to a new environment. Whereas we may expect additional information to accrue from this experience which will enable a closer approach to optimization, the primary purpose of a pilot period is to generate engineering and operating data within the specific environment to enable an economic and practical scale-up of the system to full production. However, since we may expect a 90-day grow-out period, one may achieve a harvest during the first year. If this harvest confirms the assumptions, one may consider this to provide sufficient engineering and operating data to support the decision to proceed toward full-scale production promptly.

Alternatively, one may elect to accomplish several additional harvests before scale-up, but it is our judgment that the checkpoint need not be deferred beyond 24 mo after day one.

It is our best judgment at this time, based upon our previous experience in the management of aquafarms and our understanding of the tasks to be performed, that a modular farm of about 200 acres represents a unit which can be managed by a competent farm foreman and a crew of laborers. This concept of a module should be factored into a plan, and may be judged to represent a second checkpoint on the time/size scale. Whereas this size is dictated by management-labor, feed storage, harvesting, etc., it does not prove to be of sufficient size to be economically viable for an investment program. It could, however, be a very good size for a single owner-manager operation if it were properly supported with juveniles for stocking, feed, and other such critical inputs. We make reference to this matter here primarily to indicate a land unit that should have sufficient production to justify a consideration for its separate existence. By this we mean that even though we are advocating here an aquafarming venture that will ultimately utilize 2,000 acres of water for production, we are saying that these need not be contiguous acres, but can be developed in separate increments of about 200 acres each. As long as these separate farms are within an appropriate radius of both a farm headquarters which can supply juveniles for stocking grow-out ponds, technical pond

management backup, feed supplements, etc. and a processing plant which will prepare the product, they can be integrated into a system.

We have concluded that three such farms, or 600 acres of grow-out production, constitutes a sufficient business scale to stand alone as an industrial entity. This will generate sufficient income to provide an acceptable return on investment. However, at this point on the growth curve of the enterprise, a small processing plant is warranted. We propose a labor-intensive processing operation.

This was done because we are convinced that there are considerable economic advantages to be realized from a fully integrated enterprise in which processing and marketing are operated concomitantly and coordinated with production.

We have not at this time isolated processing and marketing as a separate profit center although this can readily be done. In a vertically integrated, balanced system, it is axiomatic that all major components should be intimately coordinated and operated at a flux-equilibrium if we are to achieve the advantages of optimization of the technical and economic sectors of the system. In order to achieve this condition we have carried our analysis to the 1,000- and 2,000-acre production scales. This will provide an input into the processing plant, and subsequently into the market place, of a sufficient volume of product to allow for optimization of the food processing technology and a sophisticated marketing program. It is anticipated that a high degree of processing efficiency can be achieved employing a wise mix of hand labor and mechanization to enable efficiency, control of quality, versatility in product form, and a certain amount of social profit by the creation of jobs in a society having excess labor.

Since we have not at this time achieved optimization of the many influences on production cost (such as feed formulation versus cost per pound of production; pond management to enable high natural productivity so as to provide low cost forage upon which the shrimp can grow without complete reliance on formulated rations; reduced mortality by reduction of environmental stress, predation, disease, etc.) we cannot categorically state yields and consequent costs. However, for the purpose of this analysis we have elected to use what we judge to be a conservative yield of 3,000 lb per acre per year, which we have already achieved.

We expect, after the pilot phase has been completed, to acquire sufficient additional understanding of the performance of the system in situ to realize higher yields such as 3,500 or 4,000 lb per acre per year.

Similarly, we have used a feed conversion ratio of 2.5:1 and a cost per pound of formulated pelletized ration of 14 cents/lb. We judge these to be very conservative figures.

The prospect of the establishment of a large number of successful crustacean aquafarms in the Middle American costal and freshwater environments within the next few years is not very great. On one hand the high capital investment required to establish the reasonably large-scale facilities needed to be economic and the limited number of sites that can provide favorable competitive advantages, on the other, will in my judgement, curtail the number of profitable undertakings. Furthermore, the level of business management sophistication and technical know-how will confine such activities to a very few.

One mechanism to achieve the advantages of economic scale, while at the same time enlisting the involvement of a large number of small landholders, may be through farm cooperative organizations which can provide technical assistance and engineering guidance for pond design and construction as well as coordinate the function of juvenile production for stocking privately owned grow-out facilities, feed production and distribution, and even a custom harvesting service.

Alternatively, a private enterprise organization can provide the services that can be provided by the cooperative noted above to individual small-scale farmers and can justify its efforts by contracting for the production to be processed and marketed from a central facility. This would allow the associated growers to operate individual farms, which would make them, in effect, correlative with captains of privately owned trawlers selling their catch to a central processing plant.

Because of the high production costs and the commensurate high selling prices commanded by these high-value products, crustacean aquaculture in the Middle Americas is not likely to make a significant contribution to freedom from hunger for those people in the developing world where dietary protein deficiencies are prevalent. It may, however, make a significant contribution to economic development by generating foreign exchange, contributing to growth of infrastructure, and, most importantly, by providing employment in the rural sectors of certain Middle American societies.

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MFR PAPER 1115

Institutional Constraints to the Development of Aquaculture

FERNANDO FOURNIER

It is very important in this field to determine in each case which authority is capable of issuing rules or provisions designed to regulate activity in each of the categories of waters in the world. I shall therefore attempt a case-by-case analysis.

ON THE HIGH SEAS

One of the few areas where prevailing international law on maritime matters has clear and definitive provisions, accepted by all nations, is the one involving effective authority on the high seas. This authority is the international community, for all countries recognize that the high seas belong to mankind as a whole and that consequently no one country can claim sovereignty or rights over them; this being so, only the community of nations can establish legal rules applicable to that portion of the earth's waters. Legal provisions have been established in the past with respect to other subjects which have the high seas for background, such as piracy, collisions, over-exploitation of fisheries, etc.

Nevertheless, thus far no international convention has been drafted which establishes a legal system with respect to the potential use of the waters of the high seas in activities such as aquaculture whose development is deliberate and rational. There is no doubt that it would be highly desirable for the United Nations or some other world authority to undertake the task of establishing such a legal system.

THE CONTIGUOUS ZONE

The various states recognize that, in addition to the territorial sea, there exists an intermediate zone between the territorial sea and the high seas. There is considerable uncertainty in the world about the exact delimitation of the territorial sea, and this fact, which we shall be examining shortly, must be kept in mind in order to conclude that, consequently, the contiguous zone is not precisely determined since its location in the various seas depends in large measure on the recognized breadth of the territorial sea.

In any event, although its situation is somewhat uncertain, the so-called contiguous zone is fully recognized in international law, and various national and international rulings have been made with respect to it, notably the Convention on the Territorial Sea and the Contiguous Zone, to which 81 sovereign states adhere. This Convention does not grant coastal states any exclusive fishing rights, but it does grant them the power to establish certain restrictions in the interests of regulating customs, fiscal, immigration, and sanitation matters. The jurisdiction involved is restricted but nonetheless important for this study.

The authority granted coastal states over this zone could be interpreted to mean that those states are capable of regulating certain activities that might in one way or another threaten aquaculture in nearby regions, and this can give rise to regulatory measures of significance to this discussion.

THE TERRITORIAL SEA

The Convention on the Territorial Sea and the Contiguous Zone clearly establishes the authority of the coastal state over the belt of sea adjacent to its territory, so regulatory authority over the territorial sea is established by clear and categorical provisions of current international law. Also in effect is a Convention on the Continental Shelf, done at Geneva in 1958 and ratified by many nations. The continental shelf in many cases almost or partially coincides with the territorial sea. Nevertheless, the latter's exact breadth has yet to be determined, and this is the point on which, at the present time, not a single clear rule exists. For many decades a 3-mile breadth was accepted for this zone, but in recent years many countries, by now perhaps the majority, have adopted greater breadths. The rationale is that the 3-mile limit is unrealistic, given, on the one hand, the far greater distances over which countries can now exercise surveillance and, on the other, modern technical means that permit intensive exploitation of the sea's resources over much greater areas.

In other words, one could say that in present-day international law there is a uniform criterion for determining the regulatory authority for all kinds of activities in this zone of the sea adjacent to countries' territories—but what is this zone? The differences range from the traditional 3 miles to the 200 miles claimed by many Latin American countries. The lack of a uniform standard has even led to serious conflicts between the authorities of some countries and fishing interests, and at the time this paper is written the same uncertainty prevails.

Another point requiring clarification in certain cases, especially with respect to federally organized countries, is the determination of which authority of the coastal country should direct and regulate related matters inasmuch as uncertainty can arise as to whether that authority should be exercised by the federation as a whole

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or by each of the states into which it is subdivided. This is still a highly controversial question in many countries.

INLAND WATERS

In the field of international law there is no doubt that authority to regulate any activity in waters within a country's territory belongs to that country. Discussion may arise regarding which internal authority can make what regulation and which has jurisdiction to issue orders or controls on the subject. In most federally constituted countries of Latin America it would seem to be the criterion that these matters are the responsibility of the Federal Government. In the United States the point has not been so clearly defined, although the prevailing thesis appears to be that the individual states have jurisdiction, at least until the Federal Government enacts clear and definitive legislation to assume it.

Keeping in mind the foregoing analysis of the uncertainty about which authority should issue regulations regarding aquaculture, we can proceed to discuss what clear and definitive provisions may exist in the world, and especially in the western hemisphere, to cover this type of activity. We have already said that no clear regulations covering aquaculture exist with respect to the high seas, where the jurisdiction of the community of nations appears unchallenged. Authority over the other aquatic zones obviously devolves on the countries which exercise jurisdiction over them, although uncertainty remains as to the identification and especially the location of those zones. At the same time we are faced with an almost total absence of concrete rulings that might offer guidelines for the development of aquaculture.

Some Latin American countries have passed fairly comprehensive laws concerning fishing activities, particularly Mexico, Guatemala, and Peru. However, these laws contain little that refers directly to aquaculture; they are almost totally limited to provisions regulating traditional fishing, while the application of artificial means to promote the growth of aquatic organisms, the rational and artificial development of those organisms into colonies, and the problems caused by this type of activity are virtually ignored.

In the other countries, which lack even comprehensive legislation on fisheries, still fewer provisions exist. Consequently, they are without the means to resolve many of the problems that aquaculture would bring. Almost all of them have general legislation covering coastal property rights and the use that men can make of public bodies of water; it generally establishes priorities for such use, and fisheries, under which aquaculture would come, are in most cases relegated to one of the lowest priorities, after industry and sometimes after navigation. Everyone realizes that this would make the development of aquaculture difficult at a time when it would require legal protection to defend itself against the danger posed by industry, with its tendency to pollute, and by navigation.

There is the separate matter of the policy to be followed for the rational use and proper conservation of the natural resources which are the objective of aquaculture. This is currently an issue of much interest that relates directly to the purely legal aspects of the matter and may determine to a great extent the legislation that will have to be adopted regarding it.

On the one hand is the sound and lofty aim of helping man develop and use all the resources with which nature has blessed him. On the other is the very commendable point of view of those who have begun to observe with alarm how natural resources, including those of the sea, are shrinking in proportion to the man's needs, especially in view of the threat of excessive population. This latter concern causes countries to try to protect all the more zealously the natural resources with which they are blessed, as they come to fear their disappearance before they can be used. Without conscious chauvinism but simply in a spirit of eagerness to protect the very subsistence of their inhabitants, there is a widespread and growing tendency among countries to preserve such natural resources for themselves.

This tendency is especially understandable when countries are confronted with activities that could somehow damage or destroy the resources contained in their waters without benefiting their own citizens or those of other countries.

Such attitudes, as long as they are not carried to absurd extremes, are perfectly proper, understandable, and admissible. Private international enterprise must get used to the idea that restrictions stemming from such proper national aspirations are to be expected as reasonable actions, and that countries, as they realize the need to enact laws to regulate aquaculture, will probably, in the majority of cases, include provisions reflecting the aforesaid concerns. Public opinion, however, must keep in mind the need for intelligent regulation of aquaculture which avoids wasting a country's natural potential and accepts, on an equitable basis, the technical and economic assistance that is often unavailable within its own borders.

Fortunately, the fact that there is virtually no legislation pertaining to aquaculture on the books makes it possible to plan for the adoption of laws which would take into account the foregoing points of view and coordinate them in a just and equitable manner.

We must keep in mind the welfare of the people of countries that are starting to draft legislation on aquaculture that will control activities rationally and fairly. We consider it advisable for some international organization, whether of an official or private professional nature, to undertake study on what a model law in this field should include. It might be undertaken by an international organization such as the United Nations or the Organization of American States, or by private professional groups such as the Inter-American Bar Association.

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MFR PAPER 1116

Constraints on Aquaculture Projects

BURTON A. LANDY

It is not to be unexpected that international and domestic legal regimes at present do not fully accommodate themselves to the practice of aquaculture. Although admittedly practiced for some time in isolated parts of our planet, the technology prerequisite to the successful commercial exploitation of aquaculture has not until recently been available. In fact, in more cases than not, viable technologies have not as yet been fully perfected. And in those instances wherein aquaculture practices have been technologically possible, economic considerations have forestalled development in influencing decisions to opt for cheaper food production on land surfaces.

These technical and economic considerations have had a direct bearing on the lack of development of the law regarding aquaculture. Basically, a void of technology coupled with high economic costs has in effect eliminated the necessity for the law to consider how aquaculture is to fit into the scheme of things.

Therefore, in considering institutional constraints on the development of aquaculture, we must approach legal regimes analytically and carry forward principles in order to accommodate new realities. Legal regimes may appropriately be viewed as establishing lines of division whereby relationships are defined either between or among competing uses or practices, or between or among competing persons and institutions. Thus, it is the function of the law to define and establish the rights and relationships between these competing forces. Of course, these dividing lines must of necessity be adjusted from time to time as new elements spring into existence. At first it may seem that these processes are so very unpredictable that there is no relationship to scientific analysis. However, it may well be that the law is simply a product which is a function of time and the composition of which is dictated by an infinite number of imputed factors which are in an everlasting process of adjustment.

Aquaculture has not heretofore gained the attention to effect, nor displayed the requisite forces to command, a noticeable adjustment. Thus, at this point in time the law more often than not either is silent with regard to principles directly addressing themselves to aquaculture or, perhaps more likely, is expressed in favor of a competing force or use. Therefore, there are indeed at present substantial institutional constraints on the development of aquaculture which are expressed by law.

The relevant inquiry then becomes, first, what at present are these institutional constraints, and second, how is the dynamic of law likely to change.

PUBLIC CONSTRAINTS

Navigational Rights

Navigation has been a traditional use of the high seas, and freedom of navigation on the high seas has been expressly recognized in some of the most basic expressions of the law of nations, such as, the Convention on the High Seas. However, the freedom of navigation is not an absolute, but rather gives way to some extent to other freedoms, for example, fishing. Although traditional definitions of fishing may not necessarily include such an activity as mariculture, the question is an open one whether such a new use for the high seas may coexist with such a traditional one as navigation. However, considering that the present law is but an outgrowth of the practice of nations, it is readily foreseeable that mere increased usage of aquaculture may result in its legal recognition as a proper, lawful, and reasonable use of the high seas. In any given case, it is apparent and compelling that the only workable test would be reasonableness, and it may rather persuasively be argued that an activity which is mobile, i.e., navigation, should yield to an activity which is essentially stationary. Mariculture projects of limited size and apart from traditional sea lanes certainly could not, for those reasons, be said ipso facto to be unreasonable uses of the high seas. Finally, it cannot be doubted that an activity resulting in the feeding of a population is reasonable.

In the territorial sea there exists the right of innocent passage for foreign vessels which has been memorialized by conventions. However, the right to innocent passage also is not absolute. There is, of course, the duty of the coastal state to not hamper innocent passage and to give publicity to dangers to navigation. It is not mandated that there be no dangers to navigation, but only that adequate notice be given so that a vessel may avoid the particular problem. Thus, a mariculture activity not totally obstructing innocent passage and for which adequate notice is given should not be in violation of this right. Further, it is lawful for the coastal state

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to prescribe rules and regulations for the navigation of ships exercising the right of innocent passage. Therefore, if a coastal state exacts of users compliance with its navigational routes, which are reasonable in nature and which compel the circumvention of, and thereby protect, a mariculture activity, there should be no violation of this established principle.

Just as in the international community foreign vessels have a right of innocent passage, there is also a right for nationals to enjoy free navigation. However, such a right is not exclusive in nature. Consequently, there is no reason why government may not impose reasonable regulations in the exercise of its police power and in support of its proper and recognized interest in the public health, safety, and welfare to limit navigation from areas wherein there is aquaculture activity. And, again, such restrictions would appear to be ipso facto reasonable if in support of a paramount governmental concern such as the feeding of its population. This theory not only supports the exclusive utilization of certain limited areas for mariculture activity, but it also can be extended to protect and allow the construction, when necessary, of dams, dikes, wharves, piers, and screens.

Finally, in those states wherein the supporting society has granted its government the right to enact positive law in support of the power to regulate and further commerce, a legal theory supporting legislation in aid of aquaculture could be advanced that such legislation is supportable under the commerce power, since the activity is in furtherance of commerce.

Fishing Rights

The freedom of fishing, like that of navigation, is recognized in international law by express language in relevant conventions. And, as with navigation, this freedom is not absolute. Although an aquaculture project requires the exclusive use of particular waters, it does not draw necessarily upon the fishing resources of the area. Therefore, while the aquaculturist may exclude others from fishing within the particular waters, he does not deplete the natural fishing reserves. To the contrary, in certain projects, e.g., shrimp farming, hatchability may be so extensive that the excess could be cast into adjacent waters and thus increase the supply for conventional fishing.

There is also some precedent in international law, as established by the custom and usage of nations, regarding an exclusive use of waters to which fishermen are denied access. This concept finds expression in the exclusive use of waters for naval maneuvers, for the testing of nuclear devices, and for the testing of missiles. Also, as a matter of custom, traditional fishermen themselves are sometimes exclusive users of waters in that the use of dragnets by large fleets of fishing vessels excludes others from the immediate area being fished. A similar usage is a permanent installation attached to the floor of the sea in support of traditional fishing. This practice is, in fact, supported in law by the Convention on Fishing and Conservation of the Living Resources of the High Seas.

Cables and Pipelines

The aquaculturist "possessing" rights to a certain area should be compensated for a "taking" by eminent domain if cables and pipelines are placed nearby under governmental auspices and damages are sustained. These cables and pipelines can, of course, completely ruin a project. Of course, both aquaculture and cables and pipelines may be in the public interest, and, therefore, a balancing of needs and interests must be made.

Recreational Rights

The rights of the public to use waters for recreational purposes must be recognized. These rights, among others, include bathing, boating, and fishing. However, the police power of the state can be used to deny them for other valid and/or superior purposes. With an increasing worldwide population, aquaculture over time will, no doubt, be determined to serve a greater purpose. The state already has: (1) jurisdiction over "public" waters; and (2) the police power. Therefore, all that remains is the public policy determination.

Pollution and Water Quality

Pollution is currently becoming a paramount problem in the industrialized nations of the world. As more and more waters become polluted, the developing countries will of necessity also become concerned with this problem. Undoubtedly, coastal areas, where aquaculture projects are the most possible and promising, will be affected. Some of the problems to be faced are:

1) Municipalities and riparians discharge sewage and rubbish into waters.
2) Chemicals utilized for crop spraying may wash downstream.
3) Oil spills may develop.
4) Industrial pollution of all types is ever increasing.
5) Siltation resulting from dredging and filling operations will increase.
6) Predator fish which victimize aquaculture often are attracted to pollution areas.

Not only international law problems are involved, but there may be conflicts in the internal laws of certain nations as well. For example, the United States Constitution grants to the Federal Government exclusive jurisdiction over admiralty matters; however, recent court decisions have held that pollution control is primarily in the hands of the state and local governments. There is, nevertheless, a growing realization that industrial pollution may be too big a problem for the state and local governments to handle by themselves.

These various competing forces are constantly working. There can be, however, a combination of interests between aquaculturists and "downstream" cities and property owners, i.e. obviously both want and need clean water.

PRIVATE CONSTRAINTS

Riparian Landowner's Rights

Definitions might be a proper point of beginning. "Riparian" is a term which refers to that belonging to the bank of a river or other watercourse. "Littoral" is a term which refers to that belonging to the shore of the sea, lake, or other tidal body which does not possess the characteristics of a watercourse. Here the

term "riparian" shall be used for both, since, on principle, there is often little difference between the two.

A riparian owner is a landowner whose property borders on a body of water. Whether land "borders" on a body of water is a legal question which is resolved in a particular jurisdiction as a matter of definition. For example, a landowner may by law be entitled to riparian rights in a body of water if the property which he owns extends to the ordinary high-water mark.

Rights attaching to the riparian owner are those incident to his being adjacent to the body of water. These rights usually inure to the benefit of the riparian owner although in a strict legal sense they are not "owned" by him. These rights may include those of ingress, egress, boating, bathing, fishing, as well as a right to an unobstructed view and a right to construct a pier or wharf to the point of navigability.

These rights may, of course, present serious practical difficulties to the practice of aquaculture; and, since they are characterized usually as "rights," one desiring to practice aquaculture must deal with each even though the riparian owner may not at a given time be in the exercise of any one or all of them.

The right of ingress and egress entitles the riparian owner to access upon the water from his land to the point of navigability. This right is not customarily expressed in relation to the size of the vessel utilized. Thus, for example, the aquaculturist cannot rely upon the continued use of a canoe by a riparian but should be prepared to guard against subsequent utilization by a power boat which might disrupt the reproduction cycle of a particular culture. Another right sometimes concomitant with riparian ownership is that of ingress and egress to the main body of water. Therefore, the aquaculturist may not be able to rely merely on rapprochement with adjacent riparian owners, but must also in such cases secure a harmonious relationship with those more distant. These problems are especially acute when it is necessary, by the erection of a dam or dike, to close off a lagoon, bay, or creek.

Of course, the aquaculturist will experience few problems if he himself enjoys the status of a riparian and if the aquaculture activity does not interfere with an adjacent owner. Indeed, it may be, as a matter of production, not only advisable but even necessary to support the aquaculture activity from land installations. Thus, land ownership or use may at once satisfy a technical production need and eliminate a legal constraint.

Another associated consideration is the patrimony of the state which, although perhaps not to be strictly classified as a "private" constraint, is of a similar nature. In those jurisdictions where the national patrimony includes coastal and/or submerged lands, the aquaculturist must be prepared to deal with governmental authorities and negotiate appropriate leases.

SUMMARY

It would appear, in summary, that these various rights and constraits are, as a matter of historical understanding, but functions of uses. Aquaculture, as it becomes viable on account of technological possibility and economic feasibility, is a new use. As this new use is practiced, undoubtedly legal regimes will accommodate it not only to existing provisions of law, but also to a rule of reason and a test of reasonableness. Finally, as aquaculture becomes not a mere possible use but rather a social and practical necessity in order to feed the populations served by the rule of law, a particular legal jurisdiction will of necessity adjust either with ease and speed or with that social pain so often experienced when a society fails to recognize correctly its own necessary priorities.

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MFR PAPER 1117

Net-Pen Culture of Pacific Salmon in Marine Waters

ANTHONY J. NOVOTNY

ABSTRACT — The concept of floating net-pen culture of fishes in marine waters has been expanded to include Pacific salmon, Oncorhynchus *spp., in the Pacific Northwest. The National Marine Fisheries Service initiated the research in Puget Sound, Wash., in 1969 with small (2.7 m^3) net enclosures. The rapid growth and reasonable survival of cultured coho salmon,* O. kisutch, *led to the development of a pilot farm. The farm utilized a surface area of 0.1 ha with four net pens totaling 7,080 m^3 in volume. A total of 61.4 metric tons (mt) of 170- to 380-g Pacific salmon were shipped to market within 18 mo after fertilization of the eggs. Coho salmon have been raised to maturity in seawater pens in 2- and 3-year cycles. Survival of both brood stocks and fertilized eggs from cultured salmon is variable, however, and improvement is needed in controlling disease and nutrition. Bacterial pathogens are a serious problem. A vaccine for the control of vibriosis, the most prevalent disease, appears to be successful but needs further study and evaluation. Net-pen culture is being practiced in Puget Sound waters for two purposes: (1) the commercial production of pan-sized Pacific salmon by private farms and (2) the extended rearing of hatchery-produced salmon for release to the local sport fishery. Total sales in early 1973 of privately farmed fish were over 40 mt and were expected to rise to 1,800 mt in 1974.*

INTRODUCTION

Pacific salmon, *Oncorhynchus* spp., reproduce in fresh water of the highest quality. Losses of salmon stocks from damming, logging, pollution, etc., coupled with the rising demand for salmon as food, have led to extensive investment in artificial propagation to augment the natural runs. During the last 100 years, salmon hatcheries on the Pacific coast of the United States have evolved into expensive systems under constant economic scrutiny. In many areas rising capital costs and the limited fresh water will prevent much new construction or expansion of salmon hatcheries. Therefore, to expand the present levels of production we must seek new, economical methods of salmon culture.

In the Pacific Northwest, the National Marine Fisheries Service (NMFS) began culturing salmon in floating net pens in 1967. The plans originally called for large-scale culture in the freshwater reservoirs behind the dams on the Columbia River and, by 1969, the concept was expanded to include the marine environment.

The marine culture of salmonids is not new. Rainbow trout, *Salmo gairdneri*, and Atlantic salmon, *Salmo salar*, are being cultured in Scandinavia and the British Isles in seawater (Novotny, 1969 and 1972). Rainbow trout and, to a limited extent, Pacific salmon are being cultured in seawater in Japan (Tomiyama, 1972), (N. Yoshikawa, Japan Marine Photo Studios, Tokyo, pers. commun.). Although some of the culture methods involve ponding, in most of these countries there is some floating cage or net-pen culture.

NMFS research in the marine culture of Pacific salmon is now being

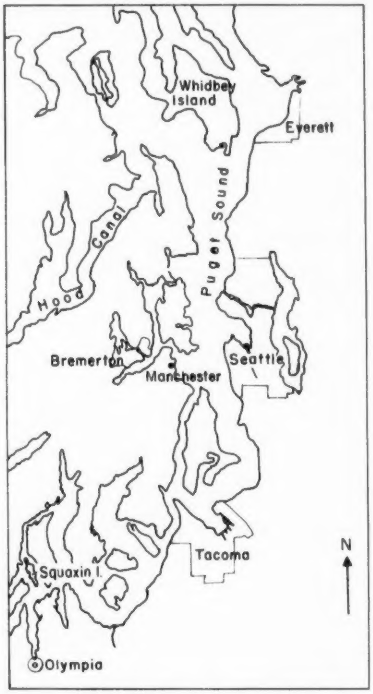

Figure 1.—Puget Sound, Wash. This inland arm of the Pacific Ocean is the site of major activities for the marine culture of Pacific salmon.

conducted at a research station on Clam Bay in Puget Sound near Manchester, Wash. (Fig. 1). This site has the advantages of good water exchange from tidal currents, narrow annual ranges of water temperature (6.5-16°C) and salinity (26-31 ‰), shelter from the wind, depths to 30 m, and a small freshwater stream entering at the head of the bay.

The general objectives of the salmon research at the NMFS Manchester station are: (1) to determine the most economical methods for commercial

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culture of salmon in net pens and (2) to determine the feasibility of modifying migration patterns and improving the survival of Pacific salmon at sea by raising them in net pens before their release. If successful, the latter technique should increase the contribution of artificially reared salmon to sport and commercial fisheries.

Other aspects of the NMFS program involve research on systems for accelerating the freshwater growth, the relation of temperature and ration to growth in seawater, brood stock development, control and prevention of diseases, possible uses of hybrids, development of fish-feed supplements from new resources, and effects of large-scale production in the saltwater environment.

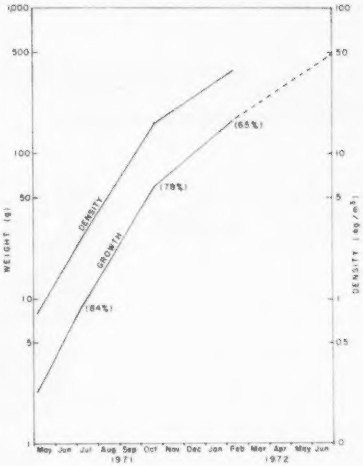

Figure 2.—Growth, rearing density, and survival of hybrid Pacific salmon (♀ *O. tshawytscha* × ♂ *O. gorbuscha*) in a small floating net pen. Pen volume is 2.7m³. Percentage of survivors is in brackets and the broken line indicates frowth after transfer to a larger pen.

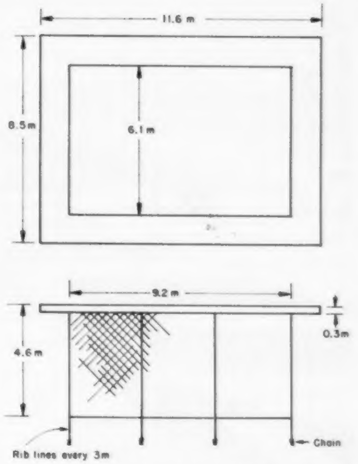

Figure 3.—An experimental production raft and net pen. Raft construction is of lumber, plywood, and Styrofoam billets. Pen volume is 258m³, and production capacity is approximately 4,000 kg of salmon.

NET-PEN CONSTRUCTION

Experimental Pens

The basic requirements for maintaining net pens in salt water are: (1) some type of surface support such as a raft, barge, ship, or dock; (2) a system for holding the headropes of the net pen above the waterline; (3) a mooring arrangement; and (4) a means of holding the bottom of the pen down and keeping it spread open.

The intensive cultivation of fish requires appropriate concentrations of dissolved oxygen, ranges of water temperature, and removal of waste by-products. In Puget Sound, the necessary water exchange for floating net-pen culture is provided by tidal currents. The effects on net enclosures of currents, fouling, and materials have been thoroughly studied in Scotland and Japan (Milne, 1970 and 1972).

The NMFS salmon culture research at Clam Bay began with a base of operations on a vessel moored to a dock. Floats with the top surface the size of a standard sheet of plywood (1.2 × 2.4 m) were filled with Styrofoam[1] billets. The floats were linked together with cable to provide a perimeter enclosure for hanging the net pens and a walkway for conducting work safely. The first pens were actually cages, made of lumber frames with rigid polyethylene plastic screening. These cages were expensive and too heavy for one man to lift. At high stocking densities, contact with the mesh caused scarring of the eyes of the fish and eventual blindness.

We then experimented with knotless nylon pens, 1.2 × 1.8 × 1.2 m. The net pens were hung between the floats and covered with black plastic. Rectangular frames were built from polyvinyl chloride pipe and filled with sand. These frames were dropped into the nets to hold the bottom open and weight the pens down. The black covers inhibit marine plant growth. Fouling occurred from marine animals but did not inhibit water exchange. These small pens were intended for use with small numbers of experimental fish. But, in one case, a group of salmon was reared at a high density to "pan-size" with reasonable survival (Fig. 2).

The superior performance of the knotless nylon webbing prompted us

Figure 4.—A variety of experimental salmon culture pens linked together. Note the black plastic covers (arrow) to prevent marine plant growth on the smaller pens.

[1]Mention of trade names does not imply endorsement of commercial products by the National Marine Fisheries Service, NOAA.

Figure 5. — Large rafts for future salmon culture experiments, ready for launching. The rafts have 5m² openings. They are constructed of Styrofoam-filled culvert material for floatation, soft iron superstructure, and heavy wood decking. They can be bolted together to form a large perimeter enclosure, from which a production net pen can be suspended.

to design larger net pens for growing larger numbers of fish and eventually for raising the fish to maturity (Mahnken, Novotny, and Joyner, 1970; Novotny and Mahnken, 1971 and 1972). Several sizes were constructed, either square or rectangular, the largest of which is shown in Figure 3. The annual production from this pen would be about 4 mt of salmon at a loading density of 15.5 kg/m³. The capital investment for this raft is less than $0.50/kg of fish produced.

The smallest complete raft-pen system that we have used holds a 2.7 m³ net pen, with a total cost of $80-100 per unit (Fig. 4).

A new experimental raft system was constructed in 1973 (Fig. 5). The units were designed to provide minimum maintenance and "break-down" construction, which is essential for the small staff at the station, and they should last many years.

Staff engineers of the NMFS Northwest Fisheries Center have also designed and constructed two floating hexagonal pen frames of all aluminum construction for the Manchester station (Fig. 6). The frames are similar to those used in Scotland (Milne, 1972) with one exception: the vertical tube members are sealed at the top and bottom and have fill pipes and air-hose connections at the top. When water is blown from the tubes, the frame has a draft of less than 1 m. The frame can then be towed to the beach on a high tide, and the net is installed on the next low tide. The entire net pen is floated on the next tide and towed into its mooring position. The tubes are filled with water until the net pen reaches the desired level. When used at the surface level (a draft of 3.7 m), the net pen has an approximate volume of 220 m³ and an annual production capacity of 2.5-3.0 mt of salmon averaging 0.3 kg. Theoretically, this unit can even be used submerged when fitted with a special tight-fitting mesh cover (we have tested a completely enclosed cage of knotless nylon (2.8 m³) in a successful experiment to rear coho salmon under the sea.

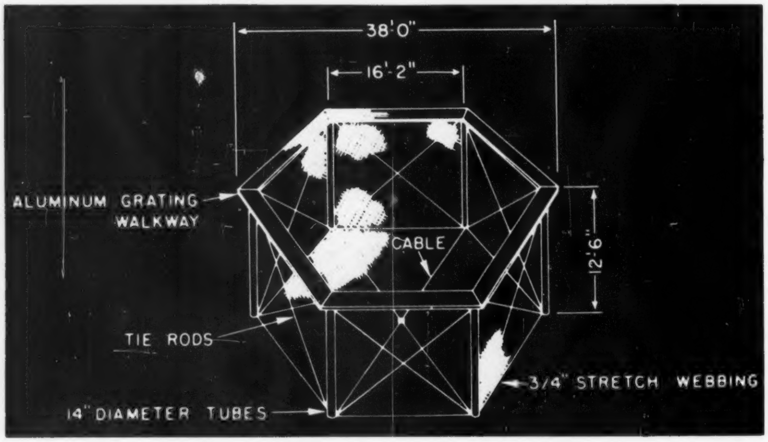

Figure 6.—An experimental hexagonal pen of aluminum construction. The head rope of the net enclosure is hung from aluminum hooks on the walkway. Six rib lines extend through the bottom and pass through pulleys at the foot of each tube. This method permits the bottom and sides to be drawn taut without weights (dimensions are listed in feet and inches).

Commercial Pens

The applications of net-pen culture to commercial production of salmonids pose different problems. Although the factors discussed previously still apply,

there are additional considerations, especially economic ones. The cost per cubic meter of growing space is considerably less for larger than for smaller net-pens. Similarly, the cost for perimeter surface support is less for large pens than for a number of smaller pens holding the same volume. However, one must carefully consider the problems of maintenance, current stress forces, and the ability to inventory or harvest fish with a minimum of difficulty. It is doubtful if there is any one unique system that is completely satisfactory, and a need exists for serious engineering tests and cost analysis.

In 1970, the NMFS began a commercial pilot farm study in cooperation with the National Oceanic and Atmospheric Administration's Office of Sea Grant and Ocean Systems, Inc. (now Domsea Farms, Inc.). The pilot farm was designed to produce a maximum of 91 mt of marine-reared Pacific salmon.

The basic raft support structure and main growing pens were designed early in 1971, and the installation in Clam Bay was completed and ready to receive fish in June 1971. The support raft was constructed of welded steel pipe approximately 0.45 m in diameter, heavy "I"-beam cross bracing, and decked with wood. Overall dimensions of the raft were 7.6 × 30.5 m. The raft was towed into position and anchored from the four corners with heavy anchors, chain, and steel cable. Water depth under the raft was about 12 m at high tide and 7 m at low tide.

Four net pens were attached to this raft. The webbing was of 126 denier knotless nylon, with 10 mm² meshes. The size of the opened nets was 15.2 m² × 7.6 m deep, with a calculated volume of 1,770 m³. In the interest of economy for the pilot farm study (i.e., the net pens were intended for only 1 year of use), a simple perimeter support system of vertical plastic pipes and Styrofoam cylinders was used. The bottom of the net pen was weighted down by lengths of chain (18 kg each) tied to vertical rib lines. The nets were held open against the changing currents by counterweighted floats attached to the outside surface corners. The entire system is presented in detail in a report on the pilot farm operation[2]. A perspective of these facilities may be seen in the aerial view in Figure 7.

A number of serious problems occurred with this system: (1) the counter-tension arrangement did not keep the nets from partially collapsing in strong currents; (2) it was difficult to keep tension on the overhead bird-net covers; (3) a large-mesh predator net had to be installed around and under the growing pens (this correction was necessary to prevent small sharks from chewing the bottom of the growing pens in their efforts to reach any dead fish); and (4) excessive stress on the webbing. The latter problem was especially serious on at least one occasion. A stress tear occurred in an upper outside corner of the growing pens. The torn section was less than 1 m from the surface, running approximately 0.25 m along the vertical and less than 1 m along the horizontal. Unfortunately the tear was in the highest density pen (estimated at that time to be in excess of 15 kg/m³)—and before the opening was discovered, an estimated 70,000 marketable fish escaped.

The first large net-pen enclosure used in Puget Sound for holding adult salmon was supported at the surface by a perimeter of floats of the same basic design as our first systems (Hunter and Farr, 1970). In southern Puget Sound, the Small Tribes Organization of Western Washington (STOWW) is applying this system of net-pen support for a salmon production operation adjacent to Squaxin Island (Fig. 1). The basic unit consists of a rectangular perimeter of floats, divided by additional floats to provide surface support for three net pens. The net pens are 18.2 m² × 3 m deep; they are protected at the bottom from sharks by an outside predator net. Each net pen has a volume of 1,000 m³. Early in 1973, 41.8 mt of chinook salmon, *O. tshawytscha*, were harvested from these three pens. The average loading density was 13.9 kg/m³.

On the basis of our experience thus far, several basic prerequisites would apply to all net-pen culture:

(1) If a mesh size approximating 5 mm² or smaller is required for the initial stages, it is far better to use many small units than one large one. Vegetative fouling occurs rapidly and restricts the movement of water through the pens.

(2) Substantial perimeter surface support is required. This is especially true for larger net pens. Wide perimeter flotation will provide:

(a) some protection from waves

(b) protection from surface debris

(c) support for the net pens

(d) safe working areas for broadcasting feed, installing and removing net pens, harvesting, etc.

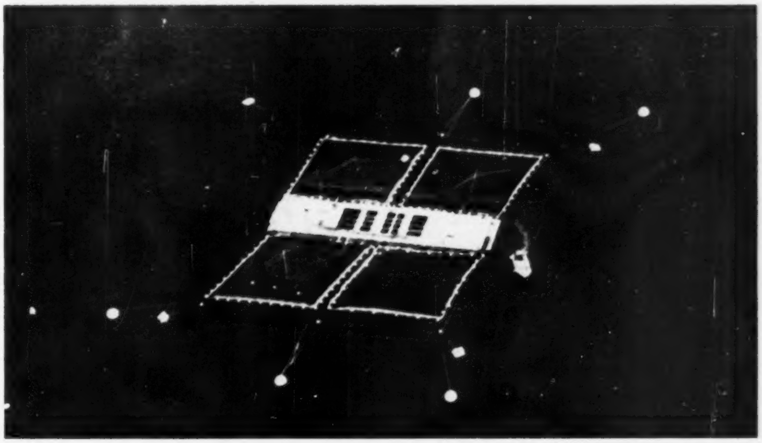

Figure 7. — Aerial view of the pilot salmon farm. Total volume of the four net pens is 7,000m³. Market harvest from the 0.1 ha of enclosures was 61.4 mt of Pacific salmon.

[2]Lindberg, J. M. [Undated.] Pacific salmon aquaculture program: Incubation and cultivation phases. Sea Grant rep. COM-73-10560, 52 p., App. A-C (Processed). Available at $3.00 per copy from D83, Technical Information Division, Environmental Science Information Center, NOAA, Washington, DC 20235.

(e) a base for bird-net covers
(f) support for winches and other mechanical aids

Although it may cost more per unit volume for smaller net pens than for larger ones, there is a substantial element of risk in large units. The old adage about "putting all of your eggs in one basket" is appropriate for net-pen culture in open waters. In my estimation, the maximum size of a production unit should be about 15 m² × 4 m deep.

GROWTH OF SALMON IN SALTWATER PENS

During the course of our studies, we made comparative growth measurements of the Pacific salmon in floating net pens—some species were studied more comprehensively than others. Five species of Pacific salmon studied, in order of increasing intensity, are: sockeye salmon, *O. nerka;* hum salmon, *O. keta;* pink salmon, *O. gorbuscha;* chinook salmon, and coho salmon. Chinook and coho salmon are now the fish of interest in our region.

Water temperature has a great influence upon growth, as do photoperiod, dissolved oxygen, nutrition, disease, and size at entry into salt water. A degradation of any one of these factors can reduce the rate of growth, which is essential for commercial production.

Fall spawning chinook salmon are cultured in most State and Federal hatcheries in Washington and Oregon. In most years, State hatcheries have surpluses of chinook eggs, but this availability is not reliable due to occasional low returns. Fall chinook salmon adapt to seawater in the first spring or summer of their life (zero-age fish). The young fish are generally reared in the hatcheries for 90-120 days after they begin feeding. They are then released into the rivers weighing 4-6 g each. Most of the releases are in late May, and the fish migrate rapidly to sea. Hatchery stocks generally return as adults after 3-4 years at sea, and range in size from 3 to 12 kg.

Fall chinook salmon have certain distinct advantages for marine pen culture. The progeny can be transferred directly to saltwater pens in the spring, which would allow greater production from hatcheries with restricted space and water flow. In southern Puget Sound, healthy chinook salmon should weigh 400-500 g within 12 mo after they enter salt water. At our Manchester station, in middle Puget Sound, the annual variations in temperature are not extreme, reaching a low of 6-7°C in late February and then rising slowly to 15-16°C in late August (Fig. 8). In most of our experiments with chinook salmon, they have been introduced to salt water in late May or early June. In general, we found that the slope of the growth curve is similar for different stocks during the summer and winter and from year to year. The salt water growth depends on the size at entry into salt water (Novotny, 1972). For example, if we begin at the same time with two stocks of chinook salmon weighing respectively 5 and 12 g, the growth curves will simply parallel each other, and during the first year the smaller stock will never catch up to the larger one.

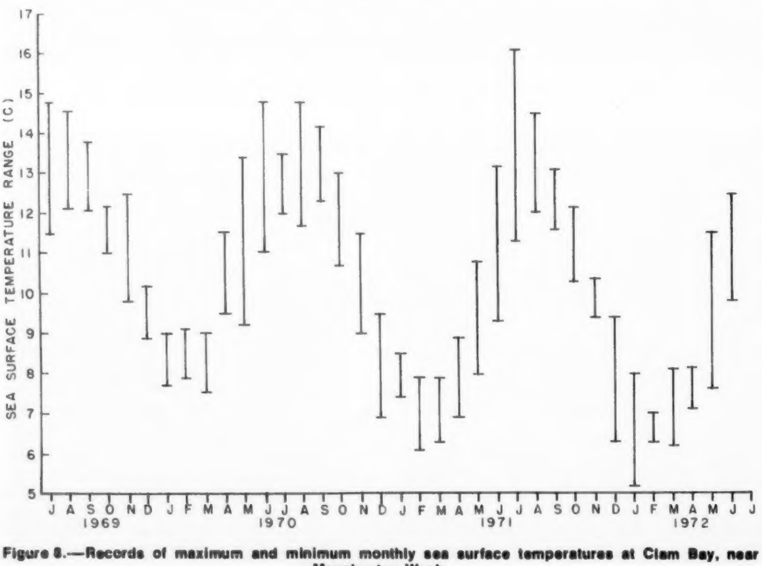

Figure 8.—Records of maximum and minimum monthly sea surface temperatures at Clam Bay, near Manchester, Wash.

Fall chinook salmon weighing 2 g can be acclimated to salt water by incremental increases in salinity (Kepshire and McNeil, 1972); however, few growers are fortunate enough to be situated where they can mix fresh and salt water readily. Most of them move their fish to saltwater pens from a distant hatchery. The tributary streams of Puget Sound warm up faster between April and late June than the waters of the Sound. Since growth can be stimulated by rising water temperature and increasing photoperiod, it can be advantageous for the grower to rear his fish in the warmer fresh water and delay transferring them to salt water until late June or early July. The timing will differ for each farm operation depending on its location.

For commercial saltwater rearing, there are several difficulties with chinook salmon. First, during their first year in salt water, their scales are very loose. This increases the risk of bacterial infection and is a disadvantage in marketing. Secondly, growth and survival have been poor on commercially available dry diets. A diet of Oregon moist pellets (OMP) produces good growth in chinook salmon but requires refrigeration for storage. The rising cost of fish meal has increased the price of pelleted diets. This, coupled with the high cost of freezer storage and less efficient conversion, will probably discourage expanded commercial culture of this species. A most critical problem with chinook salmon is that they do not resist disease as well as coho salmon. I have mentioned in this paper that the STOWW project near Squaxin Island harvested 41.8 mt of chinook salmon from their floating net pens in 1973; although food conversion ranged from 1.8:1 to 2.4:1 on a diet of 85

percent OMP and 15 percent shrimp waste (for flesh coloring), the overall survival was only 53 percent (Fraser, J., pers. commun.).

Research and development in salmon culture has been largely focused on coho. Most of the state hatcheries around Puget Sound maintain good runs of coho. Under present management practices, there is generally an annual surplus of at least 10 million eggs. The State of Washington recently passed legislation allowing the Department of Fisheries to sell excess coho eggs to commercial growers. Other legislation provides guidance in the establishment of commercial farms. Total capital investment for private salmon farming in Puget Sound is now in excess of $2,000,000.

Puget Sound coho normally spend 1 year in fresh water, migrating to the sea in their second spring. They spend 1 winter in the ocean and return the following fall as mature adults weighing from 2 to 8 kg. The usual hatchery practice is to collect the eggs from returning adults in November-December and release yearling smolts weighing 18-30 g in their second spring. The young coho are fed either OMP or dry diets.

Studies at the NMFS Experiment Station at Manchester indicated that yearlings placed directly into salt water in July, weighing 22 g and fed OMP, would grow at a rate of 2.2-3.3 percent of their body weight per day until fall, with food conversion ranging from 1.4:1 to 3.6:1. Growth rate and food conversion fell during the winter. One year after culture in salt water, the fish ranged from 500 to 1,500 g (Mahnken, Novotny, and Joyner, 1970). We also found that coho yearlings placed in our colder salt water in the spring weighing 10-12 g did not grow as well as larger yearlings, and mortality was higher. Those that survived to maturity weighed from 600 to 2,700 g. From these experiments, we concluded that if coho were reared to 16-20 g in fresh water and placed in salt water during the peak of the photoperiod, they would continue to grow well until harvest.

We tested this on a pilot scale, heating the water as necessary to hold the temperature between 11 and 14°C during egg incubation and rearing of the fry. The fish were fed a dry, pelleted diet. The objective of shortening the typical hatchery cycle by 9 mo was partially accomplished in July, when at least 50 percent of the stock weighing at least 16 g were placed directly into saltwater. The remaining coho were put into saltwater in August. Those weighing at least 16 g continued to grow well. The smaller ones reverted to a presmolt condition and either died or did not grow again until the following spring (Novotny and Mahnken, 1972). It appeared from this that the growth and survival of coho in salt water culture are dependent on their size and whether the photoperiod is increasing or decreasing at the time of their introduction to salt water.

Figure 9 shows the growth of accelerated coho during their first year in salt water compared with that of chinook and pink salmon. In fresh water, food conversion for accelerated coho fed on a dry diet was approximately 1.5:1. Market size (150-300 g) can be attained within 15 mo after fertilization of the egg in November. Year-old accelerated coho will weigh as much as 2-year-old, nonaccelerated coho. The cost of accelerating the freshwater rearing by 9 mo is more than compensated for by savings in feed, labor, and time to market.

DISEASES OF SALMON CULTURED IN SALT WATER

For salmon farms to be successful, survival to market must be improved. In our early studies, we found that with coho salmon reared at low densities, mortality ranged from 1 to 3 percent per month for the first year,

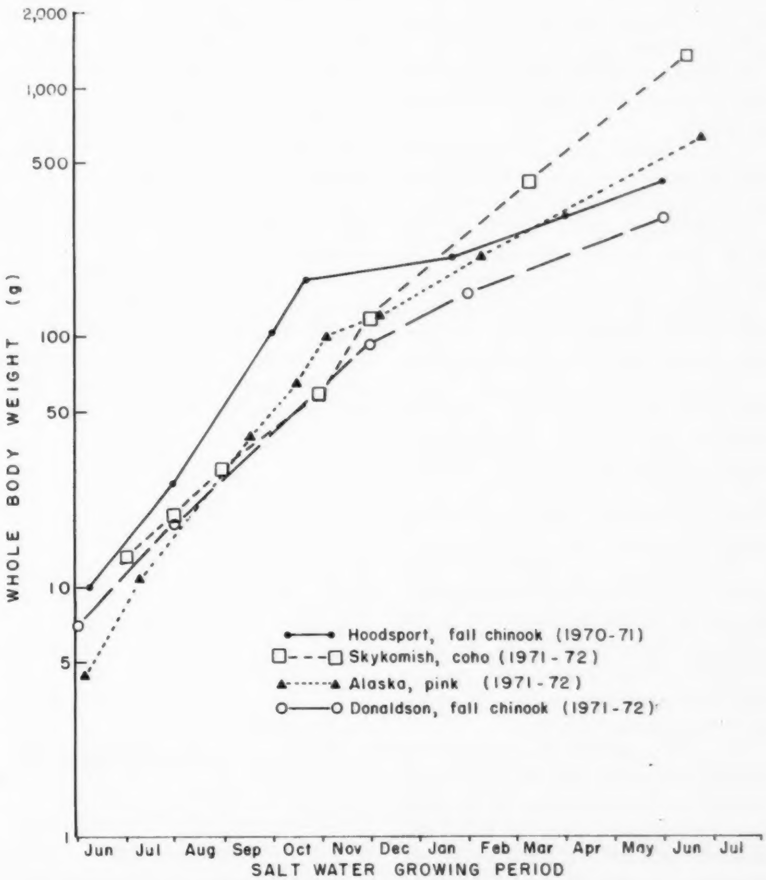

Figure 9.—Growth of three species of Pacific salmon during 1 yr in salt water. Differences between growth of the two stocks of chinook salmon (reared in different years) are believed due to differences between size at entry to salt water, water temperature, and disease influences.

the highest occurring in the summer. This would not be unacceptable. Even at high densities (Fig. 2), survival of a hybrid less hardy than coho was 60-65 percent.

The mortalities of Pacific salmon cultured in the sea are usually due to bacterial diseases. Although microbial organisms other than bacteria have been suspected as pathogens in some cases, the incidences are not frequent.

Bacterial diseases of marine fish are a worldwide problem (Sindermann, 1970), but the problems associated with the large-scale production of Pacific salmon in salt water have only recently been reported (Novotny and Mahnken, 1971). The organism that causes the greatest concern is the gram-negative, motile, comma-shaped rod, *Vibrio anguillarum*. This is the same bacterium that has been reported to cause extensive mortalities in yellowtail, *Seriola quinqueradiata*, and eels, *Anguilla anguilla* and *A. japonica*, cultured in Japan, and trout and Atlantic salmon in the Scandinavian countries.

The organism first appears in young salmon in the net pens at Manchester in May, usually when the water temperature reaches 9°C. Kidney smears from sick and moribund fish are routinely examined throughout the year. When the first cases of vibriosis are isolated, antibiotic tests are performed on plate cultures made from trypticase soy agar containing 2 percent salt. If the organism responds well to Terramycin, a therapeutic treatment is instituted. This involves oral administration of 8-10 g of active Terramycin added to each kilogram of food for 5-10 days.

V. anguillarum grows best in laboratory cultures at 24°C. Consequently, as the water temperatures rise in the summer, the probability of infection increases. The disease will usually disappear sometime in October as the water temperature drops.

Recently, attention has been focused on the prevention of the disease (Fryer, Nelson, and Garrison, 1972). Oral vaccines prepared from the killed and washed cells of *V. anguillarum* are produced commercially in the United States. The vaccine is added to the diet and fed to the young salmon prior to putting them into salt water. Oral vaccines were first used by commercial salmon farms in 1973, and the results of the field trials will not be known for some time. Laboratory experiments indicate that the oral vaccine probably becomes localized in the intestinal tract and does not provide as much protection as direct injections of the killed cells into the body cavity. A great deal of research remains to be conducted on vibrio vaccines, but I have no doubt that within the next 5 years routine vaccination against this disease will be standard procedure in salmon farming.

Furunculosis, a disease caused by a gram-negative, nonmotile bacterium, *Aeromonas salmonicida*, is also a serious problem. Pen-cultured Pacific salmon usually become infected with the organism in fresh water and carry it with them into salt water. This organism is common in most of the rivers and streams draining into the Puget Sound basin. Salmon growers in the Puget Sound basin should expect to encounter furunculosis in their freshwater hatchery systems unless their water supply comes from ground water. In fresh water, it is important to avoid excessive crowding or other stresses to minimize the incidence of this disease.

The gross symptoms of furunculosis and vibriosis in salt water are similar, and it is easy to confuse the two diseases. Usually, furunculosis does not appear until the water temperature reaches 12°C. However, we have noted that the physiological stress produced by transferring fish directly from fresh into salt water will sometimes stimulate the disease at lower temperatures. The two diseases sometimes occur simultaneously. Since the therapeutic treatment may be different for each disease, plate-culture tests should be conducted to distinguish the two organisms. *A. salmonicida* will color tryptose blood agar brown within 2-5 days at 24°C.

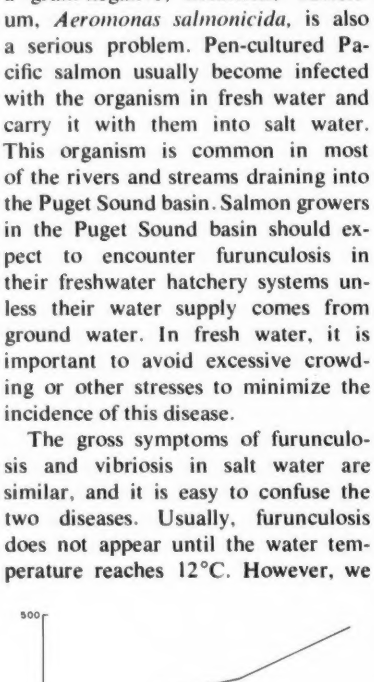

Figure 10.—Comparison of growth in two different stocks of chinook reared at Manchester during different years. Stock A suffered serious disease problems.

We found that *A. salmonicida* is transmittable at 30 ‰ salinity, and we isolated it from a diseased eulachon, *Thaleichthys pacificus*, found in the net pens with infected salmon. The organism can be grown on tryptose blood agar at 30 ‰ salinity, although pigmentation is better at 20 ‰. We found that local strains of this bacterium do not respond to sulfa derivatives when tested on Mueller-Hinton's agar and do not usually respond to Terramycin in blood agar. The furunculosis organism is inhibited by Chloromycetin, nalidixic acid, and the furinase compounds. Furox 50 (containing 11 percent active furazolidine) was effectively used to treat a large number of young fall chinook salmon in saltwater pens suffering from an epidemic outbreak of furunculosis. A level of approximately 40 g of Furox 50 per kilogram of food was used for 10 days. Prior to this treatment, over 90 percent of the fish died from either vibriosis or furunculosis over a 7-mo period.

Uncontrolled disease outbreaks adversely affect growth as well as survival. Figure 10 is a comparison of the growth of the aforementioned stock of chinook salmon with an earlier year class that was not infected. Note the extremely poor growth of the diseased stock during the late summer and early fall.

Kidney disease is a chronic bacterial infection that prevails during the winter. The causative agent is a gram-positive, nonmotile bacterium thought to be of the genus *Corynebacterium*. It does not usually occur in young fish until their first winter in the saltwater pens and is a serious problem with brood stock at any time of the year. There are no effective therapeutic agents that are known to us. Treatments with penicillin have

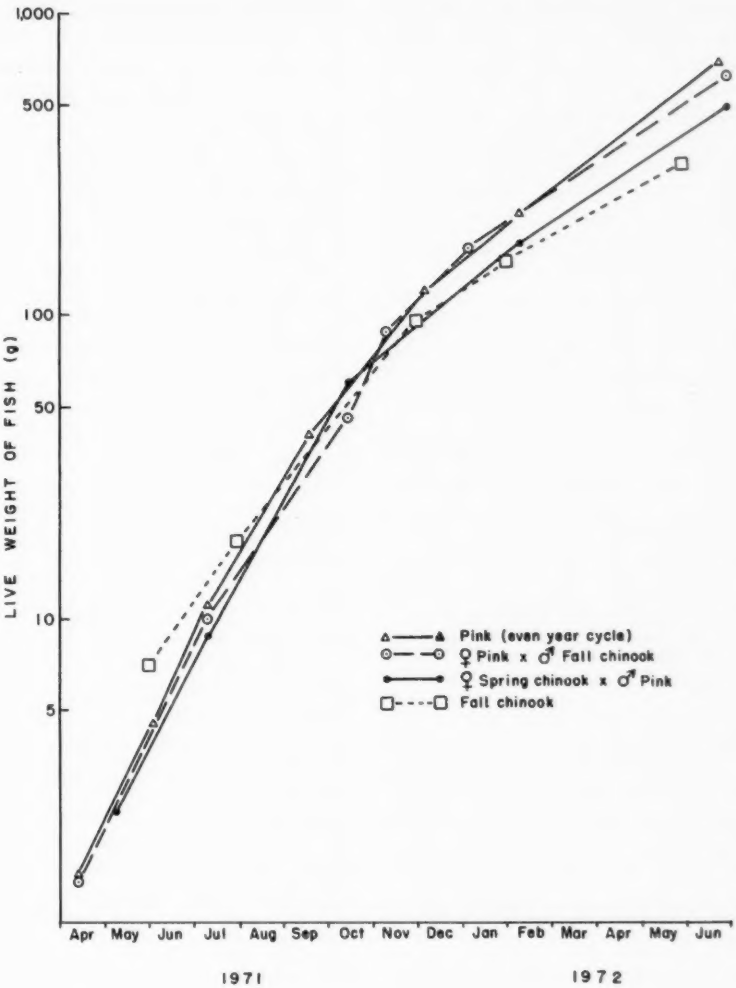

Figure 11.—Comparison of growth of pink and fall-chinook salmon (1970 brood year) reared in saltwater pens near Manchester, Wash. Two hybrids are included in the comparison.

been partially effective but only to the extent that the disease is temporarily arrested.

POSSIBLE USES OF HYBRIDS

A number of biological variations can be found in the five species of Pacific salmon common to the west coast of North America, such as salinity adaptation, temperature preference, growth, disease resistance, and maturation cycles. Although most interspecific hybrids of Pacific salmon are sterile, information from experimental hybridization has practical as well as scientific value. For example, pink salmon can adapt to high-salinity water almost immediately after they begin feeding, whereas chinook salmon cannot. Pink salmon also grow faster in the winter than chinook salmon. Pink salmon mature in 2 years compared to 3-5 years for chinook salmon.

Figure 11 is an example of the comparative growth of pink and chinook salmon and of reciprocal hybrids of the two species. In this case, the chinook female donor was of a spring-run race. Spring chinook juveniles normally spend 1 year in fresh water and migrate at a size of 30 g or more. Fall chinooks migrate to sea weighing 5-10 g in the late spring or summer before the end of their first year. Note that the rate of growth of the pink salmon and the hybrids exceeded that of the pure fall chinook salmon and that both hybrids were capable of entering salt water early in the season and at a small size.

Disease resistance also differs. The pink salmon that we reared have been extremely susceptible to vibriosis, furunculosis, and kidney disease. When reared under similar conditions, the hybrids of pink and chinook salmon respond differently to these diseases (Fig. 12). In this case, pinks and the reciprocal hybrids of chinook and pink salmon were placed in adjacent net-pens at approximately the same density. The first diseases to occur were vibriosis and furunculosis during spring and summer. The pinks and hybrid offspring of female pinks died at about the same rate until fall,

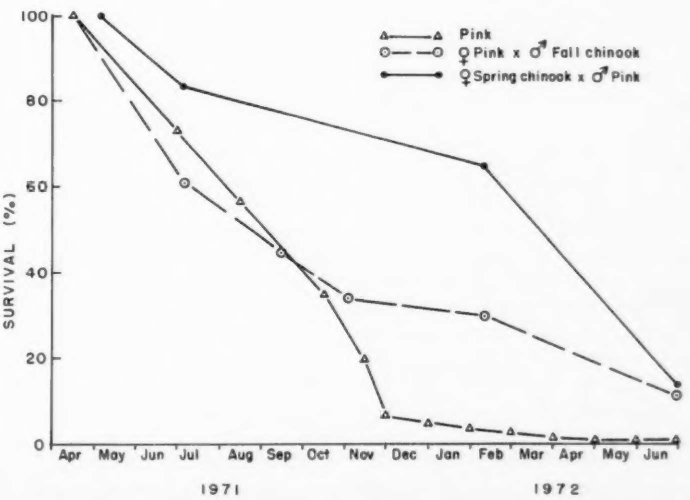

Figure 12.—Survival of Alaska pink salmon (1970 brood year) and two hybrids reared in saltwater pens near Manchester, Wash.

in spite of heavy doses of Terramycin in the diet. Survival of the hybrid offspring of female chinooks was better and fewer administrations of medicated feed were needed. As the water temperature began to decline in the fall, kidney disease appeared first in the pinks and much later in the two hybrids. Mortality in the hybrid offspring of female chinooks increased sharply in February, but this may have been due to stress. Because the survival of this hybrid was high, a stocking density of 37 kg/m^3 was reached by mid-February (Fig. 2).

The hybrids of pink and chinook salmon may be of practical value for growers who have limited sources of fresh water and wish to increase their saltwater production. When chinook eggs are available to local growers, they can b[illegible]d with pink salmon sperm, with a hatching success of 90 to 95 percent. The resulting progeny can be placed directly into seawater in March at a size of 1-2 g to provide marketable fish 12-14 mo later. The ability to adapt early to salt water in pink salmon is very strong. We crossed some of the more fertile male hybrids with female chinook salmon to produce a ¾ chinook, ¼ pink hybrid that adapts to full seawater at a size of 1-2 g.

BROOD STOCK DEVELOPMENT

Regardless of the organism being cultured, it is desirable to be able to "close the cycle," that is, be able to rear the organism to maturity, have it spawn successfully, and produce healthy progeny. This is extremely important if selective breeding is planned.

Our first attempts at rearing coho salmon to maturity began in 1970. The progeny of eggs taken from wild fish in 1967 were put into saltwater pens in July 1969 and matured in December 1970, a normal 3-year cycle. They were reared entirely on a commercial diet (OMP). The fish reached full maturity in the saltwater pens. However, the OMP diet was not adequate as the flesh of the fish remained white in contrast to the bright red flesh of wild salmon, indicating a lack of carotenoids in the diet. This lack of pigment was even more evident in the eggs which ranged from colorless to pale yellow. The eggs were soft and fragile, and the yolks were not evenly distributed. The survival through hatch was poor (5-10 percent). The alevins suffered heavy losses from rupture of the yolk sac. Some small numbers did survive, however, and after they began feeding and growing, appeared normal in all respects.

Our brood stock in 1971 came from wild eggs taken in 1968. They were also reared on the OMP diet until the last summer of the cycle. Coho put on most of their final weight during their last summer. During this period, the OMP was supplemented with the broken remnants of peeled shrimp tails purchased as a cannery waste product. Approximately 30 percent (by weight) of the total diet was cooked shrimp remnants. The flesh color of the fish improved but not dramatically. When the mature fish were taken directly from the saltwater pens for spawning, it was noted that the egg color had deepened to yellow-orange. The yolk, however, was still not properly dispersed. Survival through hatching ranged from 5 to 50 percent, compared to a normal range of 92 to 98 percent. Some of the progeny were retained and should reach maturity in 1974.

Early in 1972, between 5 and 6 percent of the accelerated coho being marketed in the demonstration pilot farm were held for rearing as brood stock. These were fish that exceeded the maximum market size (approximately 380 g). The fish were reared entirely on a dry pelleted Abernathy diet with 0.1 percent canthaxanthin added to color the flesh. We randomly selected 200 of these fish for transfer to a research pen in June 1972. Each of them was measured, weighed, and identified with a numbered strap tag on the opercle or by dart tag in the dorsal musculature. About 6.5 percent of these fish died within a few days from handling stress. The remainder were fed a diet of 70 percent whole frozen anchovies and 30 percent frozen shrimp meat waste. Brood fish in the pilot farm were grown to maturity entirely on the dry pelleted diet.

During the final 3 mo of growth, both groups grew rapidly. Figure 13 is a histogram of the weight ranges of the fish reared in the research pens. During the 92-day period between 15 June and 15 September 1972, the average weight increased by 1,360 g, an average daily weight gain of 14.8 g. The maximum weight of any individual fish on 15 June was 1,950 g and on 15 September, maximum weight was 4,200 g. Although individual fish did not retain either of the two types of tags used to the degree expected, some individual growth records are available. Table 1 shows a selection of fish that retained their tags until they died or reached maturity. Although there is a marked difference in individual growth rates, one item is evident: the maximum weight of the brood coho was achieved during the final summer and leveled off or declined with the onset of fall even though food was available *ad libitum*. The ratio of food conversion during the peak summer growing period was from 4.5 to 5.5:1 on a wet weight basis, or about 5:1. The daily weight gains of identified fish ranged from 5 to 28 g, indicating a daily food intake of 25-140 g of whole anchovies and shrimp meat waste. Although I do not recommend this as a brood diet, it is not expensive. Food costs during this period were approximately \$0.16/kg, or \$0.80/kg of weight gain during the summer.

Survival during the summer was 73 percent, but prespawning mortality was high. This was primarily due to kidney disease and occurred at a high rate on brood fish reared on the dry diet as well. Brood fish were allowed to mature in the pens and spawned in November-December 1972 as 2-year-old adults. The fertility ranged from 10 to 85 percent, considerably better than in previous years with age-3 spawners. Fertility of the brood coho reared on the dry diet was reported to be in the same range. Reciprocal crosses were made with 3-year-old wild spawners returning from the open sea to our freshwater hatchery to compare sexual fertility. We concluded from this experiment that the infertility problem was with the cultured females.

Brood fish that escaped during the transfer in June 1972 entered Beaver Creek that fall to spawn as 2-year-old fish, and the sizes were approximately

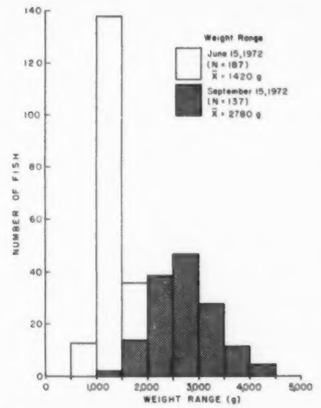

Figure 13.—Frequency distribution of weight range of accelerated coho salmon (1970 brood year) held for brood stock. During the 92-day period prior to spawning (as 2-year-old adults), the average daily weight gain was 15.4 g.

the same as those cultured in the net pens. The range of fertility was the same as for the fully cultured fish, even though they had at least 3 mo of active feeding in open waters. I can only deduce that the nutritional requirements for brood fish must be met much earlier in the life cycle than we anticipated, probably within 12 mo after swim up. This has serious implications for those farmers who want to culture brood stock. The cost of coho eggs to the growers is $6-10 per 1,000 eggs. Average fecundity of the 1972 brood of 2-year-old adult female coho was over 3,000 eggs. Thus, the value of the best brood females may be in excess of $30 each. Survival and fertility of these fish will be critical factors in the economics of brood-fish farming.

Table 1.—Growth records (1972) of individual accelerated coho salmon in the last phases of their 2-year life cycle.

Fish Number	Date of Measurement	Fish weight	Weight increase Total	Weight increase Per day
		Grams	*Grams*	
1	6-15	1,570	—	—
	9-15	4,150	2,580	28.0
	10-31	4,450	300	4.9
2	6-15	1,950	—	—
	9-15	4,200	2,250	24.5
	10- 6	4,000	−200	−9.5
3	6-15	1,650	—	—
	9-15	3,500	1,950	21.2
	11- 5	3,550	50	0.98
4	6-15	1,500	—	—
	9-15	3,600	2,100	22.8
	11- 5	3,450	−150	−2.9
5	6-15	1,480	—	—
	9-15	3,200	1,720	18.7
	9-27	3,080	−120	−10.0
6	6-15	1,400	—	—
	9-15	2,200	800	8.7
	11-27	1,760	−440	−6.0

ENVIRONMENTAL REQUIREMENTS FOR THE NET-PEN CULTURE OF PACIFIC SALMON

The most critical elements of the environment of salmon are water temperature and dissolved oxygen. In the Puget Sound area, we recommend that growers seek locations that do not range much below 8°C in the winter nor higher than 16°C in the summer. The problems of disease are much greater at the elevated temperatures. Studies relating temperature to growth and feed conversion have been conducted for several years and will provide growers with the information necessary to optimize their operations.

We found that the dissolved oxygen content of the open water varies considerably during a day. Monitors were suspended for 24 hr in the open water and in a 10-m diameter pen with 7 mm^2 mesh openings containing 8-10 kg of salmon per cubic meter. The difference between the highest and lowest concentrations of dissolved oxygen of the open water for that day was greater than any instantaneous difference between the open water and the inside of the pen full of fish.

Commercial farms in Puget Sound have occasionally experienced relatively low concentrations of dissolved oxygen in large net-pens during slack tides. Some of these pens are 20 m^2 or larger with fish densities up to 16 kg/m^3. The constant swimming of the fish creates currents that force new water through the pens. However, there are limits to this type of exchange. We have not been able to undertake studies of the practical limits of net-pen sizes at our experiment station, but we plan to do so in the future.

The effects of high-density net-pen culture on the environment are being studied at our station. In the water, the net pens present a substrate for the attachment of various species of macrophytes, molluscs, and other marine organisms. Crustaceans are attracted to the growth, and these in turn attract small fishes. Predatory fishes and birds are attracted by the smaller fishes.

The sea floor beneath the pens has attracted flatfishes and several species of crabs and echinoderms. In the vicinity of the net pens that have been in use for research purposes for over 4 years, we have not been able to observe any detrimental effects on the sea bottom. However, in the vicinity of the pilot farm operations, the effects of overfeeding were evident. The deposition of excess food on the bottom created an undesirable habitat for both fishes and sedentary organisms. Recovery of the bottom to its natural state has been slow. The problem can be alleviated by feeding no more than the optimum ration for growth or food conversion.

COMMERCIAL PRODUCTION FARMS

Both coho and chinook salmon were harvested from the pilot farm between December 1971 and June 1972. The graded fish ranged in size from 170 to 380 g. One of the purposes of the pilot farm was to determine how well the restaurant trade would respond to salmon at a size never before available—comparable to that of commercially grown rainbow trout. A number of U.S. cities were selected for the market tests, and in most cases the wholesale distributors were able to sell the small salmon (dressed, heads on, and frozen in individual packages) for $3.85/kg. In the future, Puget Sound salmon farmers who take advantage of the experience gained in the pilot farm and make the necessary engineering corrections should have little difficulty in supplying premium quality fish to a growing market (both national and international) at a profitable price. Marketable fish (0.25 kg each) can be grown at a rate of 1-5 million fish/ha/yr (depending on the depth of the net pens). Thus, it will take very little surface area to supply current market demands.

The complete accelerated growth cycle of the coho salmon from the pilot farm study is shown in Figure 14. Note that the time from first feeding to market for "pan-sized" fish is less than 18 mo. Larger fish could be grown in less than 2 years if a market should develop. At the present time, Japanese yellowtail are the only cultured marine species that can match

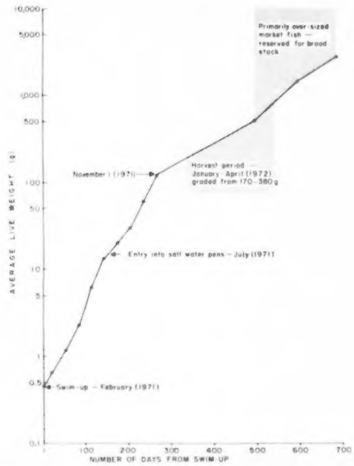

Figure 14. — Accelerated growth of coho salmon from the 1970 brood of Skykomish River hatchery stock.

the rate of growth and rearing densities of coho salmon in net-pen culture (Novotny, 1972).

Although the number of coho shipped to market was only slightly more than 10 percent of the number of eggs taken, a large portion of the loss was due to correctable engineering problems. Recent forecasts based on well-designed systems indicate a harvest of over 60 percent from the swim-up fry stage.[3] In one experiment, we were able to rear 70,000 coho from the fertilized egg to smolt size with over 95 percent survival. Moreover, coho smolts injected with a vibrio vaccine survived the critical spring and summer months (including biweekly handling for growth measurements) with over 95 percent survival, with no antibiotic treatments. I see no difficulties in projecting a survival of greater than 80 percent from the fertilized egg to market stage in the next 5 years.

ENHANCEMENT OF SPORT FISHERIES

Puget Sound, as an inland arm of the sea, is an idyllic marine recreation area for much of the year (including the winter). It is especially appreciated by sport fishermen who like to fish for coho and chinook salmon. Unfortunately, most of the hatchery-reared fish of these species migrate out through the Sound to the open sea and are unavailable to the sport fisherman except for a short time during their return as adults.

Biologists of the Washington State Department of Fisheries (WDF) found that if they delayed releasing their fish until early summer, most of the salmon would establish residency in the Sound and become available to the sport fishery on a year-round basis. However, since hatchery capacities are limited in the number of pounds of fish that can be produced, this problem could be alleviated by transferring the fish to saltwater pens and rearing them until the summer or later.

We began a cooperative study with WDF in 1971 to rear over 70,000 coho yearlings from April until July. These fish were obtained from a hatchery in the southern part of Puget Sound. Returns of marked fish from this experiment indicated they were contributing well to the local sport fishery. In the fall of 1972, the mature adults returned to Clam Bay and entered the fish ladder in Beaver Creek. The returns to Beaver Creek were between 0.6 and 1.5 percent of the number released. In Puget Sound, most hatchery returns of coho range from 0.05 to 2.0 percent. Thus, it is apparent that we can alter the migratory behavior pattern by extending the culture into the marine environment. Such a practice could have distinct advantages in fishery management.

A similar experiment in Alaska led to 15 percent returns of coho to the rearing area, allowing for expansion of limited natural freshwater habitats at minimum expense (McNeil, W. J. Auke Bay Laboratory, National Marine Fisheries Service, NOAA, Auke Bay, AK 99821, pers. commun.).

In the fall of 1972, we noted two additional groups of coho entering the Beaver Creek fish ladder. These were identified (by means of tetracycline marks in the vertebrae produced by antibiotics in the feed) as returns from subyearling and yearling (brood stock) fish that had escaped from the pilot farm experiment. The returns consisted of small 2-year-old males from the subyearling escape and large 2-year-old males and females from the broodstock escape. The brood fish (1+ years) had remained in the general area for most of the summer and contributed heavily to a local sport fishery. We estimated that on several weekends, as many as 100 of these fish were being caught per day. The early escapees (subyearlings) ranged north and south of Clam Bay, and many were taken in a number of the popular fishing areas of Puget Sound. These coho were easily recognized by WDF patrol officers because of their rounded caudal fins. This is a peculiarity of salmon reared in net pens at high density for long periods and is evidently due to abrasion from the webbing.

The return of these two groups of coho to Beaver Creek suggests that there must be a controlling factor of time release or size of fish that determines whether mature adults will return as 2- or 3-year-old spawning fish. The 3-year-old adults from the subyearling fish are expected to return to Clam Bay in the fall of 1973.[4]

Returns to the Puget Sound sport fishery of fall chinook salmon reared 9-12 mo in saltwater pens have been even more encouraging. The recovery of tagged or marked chinook salmon in the sport fishery has indicated a harvest of 15-20 percent of the number released, which is exceptional (Haw, F. Washington Department Fisheries Olympia, Wash., pers. commun.). Chinook salmon released from the net pens have also changed their migratory behavior and not only establish residency in the Sound, but also return to streams closest to the pen-rearing areas.

DISCUSSION

Initial research on the net-pen culture of Pacific salmon in Puget Sound has led to a growing number of commercial and experimental farms. This development has also led to a need for providing the technology that will increase the efficiency of all operations. Potential growth of the industry has been outlined, and an estimated 8-9 million lb of fish food will be used in

[3]Richards, J. A., C. V. W. Mahnken, and G. K. Tanonaka. 1972. Evaluation of the commercial feasibility of salmon aquaculture in Puget Sound: A preliminary analysis. Northwest Fisheries Center, National Marine Fisheries Service, NOAA, Seattle, Wash. 47 p. (Processed.)

[4]A number of large 3-yr-old adults, from these subyearling fish, did return to Beaver Creek in November 1973.

Puget Sound salmon mariculture in 1973 alone.[5] On the basis of marketing evaluations of the pilot farm study, there should be no difficulty in moving the 4 million lb of pan-sized salmon to market that are expected to be produced in Puget Sound in 1974.[6]

Interest in the net-pen culture of Pacific salmon has spread. Coho salmon are now being raised both commercially and experimentally on the east coast of the United States and are being considered for culture operations in Western Europe.

Through the efforts of past technology, we have been able to establish the beginnings of a sound farming system in salt water with the coho salmon. F_1 generations of totally cultured coho will be entering the market in large numbers.

However, a great deal of scientific information relating to salmon biology is needed by growers. We are probably at the same threshold that the poultry industry confronted 50 years ago. The fields of engineering, nutrition, genetics, and disease, along with environmental quality will all apply to salmon farming. The burgeoning problem of finding appropriate protein resources to supply the increasing demands for fish feed cannot be taken lightly. Expansion of this industry will be limited to the technological effort that is applied to it, either by private enterprise or by the government.

[5]True, E. H. 1972. The potential for producing feed for salmon culture in the Puget Sound area. MBA thesis, University of Washington, Seattle, WA 98195, 101 p.

[6]Wagner, L. C. 1972. An evaluation of the market for pan-sized salmon. Prepared for the Marketing Research and Services Division, National Marine Fisheries Service, NOAA, Seattle, Wash. (Res. contract No. N208-0344-72N), 50 p. (Processed.)

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MFR PAPER 1118

Conflict of Interest and Its Resolution as Factors in the Commercialization of Aquaculture in the Americas

SIMON WILLIAMS

My concern is to examine a conflict of interest between private investors and the nations of Latin America which I believe must be resolved if aquaculture is to become a dynamic part of economic growth and of needed social change. Stated another way, I would like to query: why does the commercialization of aquaculture proceed so slowly, when the need is so great and we know so much?

It is not my intent to present a classical economic analysis of the costs and benefits of investment—public or private—in aquaculture. You are all keenly aware, I am sure, of the enormous potential productive capacity of the vast reaches of offshore waters surrounding the Americas and edging the lakes and rivers of the hemisphere. Taken together with man-made containers, the efficient use of these waters could have a major impact on both the food economy and general economy of millions of people and every nation. I take this as a fact but will not deal with this fact in quantitative terms.

Nor will I attempt to relate in detail to the complex interplay of traditional basic feasibility factors which in a classical sense govern investment in particular enterprises. Here, too, I am sure you are familiar with the literature on the subject, or from direct experience can tabulate and quantify the elements affecting the acceptability and viability of a business dealing with aquaculture, e.g., the cost of money, technology, labor, management, marketing; obsolescence; return on equity capital; the benefits of transferred technology, employment, and training; the value to national accounts of taxes, foreign exchange savings, and earnings; and the eddy effect of the purchase of supplies and services among a myriad of others.

Rather, I would like to address myself to that aspect of the economics of aquaculture which examines the field as a material means of satisfying human desires in a broad and profound way. In coming down to this focus of attention, it is not meant to imply that aquaculturalists are prone to overlook the broad human considerations of economic development. But, whereas steady and heady advances are being made in the control of life cycles of animal species of current or potential commercial interest; in the associated fields of biological engineering to ensure efficient large-scale production; in the control of diseases and predators; in the handling of wastes; in marketing techniques; and in site selection procedures; I suspect that no comparable advances are being made in organizing the business of aquaculture so that its benefits ensure the maximum satisfaction of the people of a host country. I also suspect that it is for this reason—the fact that ventures in aquaculture are largely being considered from the traditional investment viewpoint of profit on equity—that advances in the sciences and technology of aquaculture are far outdistancing the actual application of knowledge to commercial activities.

This situation is understandable. Merely defining the diverse sensitivities and aspirations of a nation and its people or, in a more limited sense, just the people in the neighborhood of an aquafarm, is a difficult art to practice. Reducing these understandings to a workable method of dealing with them in the context of a business operating for profit is even more difficult. Yet I hold that the future growth of aquaculture as an industry of real significance for the Americas depends upon the skill with which we are able to blend our ability and our urge to do what we know how to do, with doing it within a humanistic tradition. The powerful forces of scientific curiosity, engineering ingenuity, entrepreneurship, and return on investment must be hitched to what men think is needed for their growth and joy and because they perceive what is done to be "good."

What logic can construct such a belief? One first has to react to the thrust for national development and social justice which is the outstanding characteristic of the Americas today. There are cynics, with evidence from history and contemporary affairs to support their charges, who argue that social revolution as idealized and translated into political action is just a cover for those protecting their wealth and power. However this may be, the facts as dictated by law—by the pragmatism of political leaders—by pressure from better and better organized centers of self-interest such as labor, farmers, and students—by conscious nationalism capable of violent expression—by agitation within religious and military organizations to break with conservative traditions and to

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foster rapid advancement among the poor and disenfranchised—are facts which affect a private decision to invest and a government decision to allow a business to proceed.

The law may restrict the percentage of foreign participation, project location, currency convertibility, marketing arrangements, transfer of technology, staffing patterns, the cost of labor, and even the selling price of the finished product. Politicians may promote costly social benefits as a charge against doing business, such as those related to job security, health, and housing. Self-interest groups may insist on a greater share of profit, a lesser role for foreigners, more say in policy. Violence as a tool of revolution may intimidate both public and private enterprise. Agitation within conservative institutions such as the church and the military may be hopeful signs for future progress but in the short run may engender a volatile, often explosive response to repressive forces out of the past.

Examined this way, political, social, and economic reality in the Americas logically defines the critical importance of man's felt needs to the acceptance of industrial and agricultural development (aquaculture being of both types). The search for personal dignity and national identity is going on everywhere, throughout every institution and within all strata of society. The search is energized by passion and hope and is full of vigor. To treat this probe into future possibilities as demagoguery or as being transitory, is to proceed irresponsibly and at peril. New business ventures, particularly those created through private enterprise, simply must participate in the quest for a satisfying meaning of life.

Aquaculture by its nature relates almost uniquely to considerations of the quality of life, both from the perspective of a nation and of an individual. Water serves so many purposes and competition for its use can strain human relations to their limit. Water and land use are inextricably related, not only in production terms but as well in the areas of recreation, environmental purity, and aesthetics, each in turn closely related to the demands of cultural style and to physiological and psychological health and happiness. An aquafarm may restrain access to a shoreline; it may pollute or it may require pollution control of upstream waters in rivers used as such or which feed lagoons and lakes of commercial promise. In an area of acute poverty and malnutrition, the aquafarm may be producing an expensive foodstuff for far away markets, at once whetting and frustrating the local appetite, encouraging thievery and antagonism. A region of primitive pristine beauty may be invaded with access roads, power lines, and other infrastructure requirements of an aquafarm, resulting in a predictable set of reactions. Some will object out of concern for the protection of the environment; others will decry such costly installations unless the aquafarm is but one enterprise in a complex to be served by the new facilities. The question arises: who is responsible for taking the initiative to produce an area development plan, the pioneering aquafarmer wishing to get started or the government, which might then cause long delays in implementation?

In all these instances, flagellation of human relations is a constant danger. These instances can be added to, almost without end. Aquaculture is capital intensive and calls on sophisticated technology and highly skilled management, neither generally available in the Americas outside of Canada and the United States. Insofar as Latin America is concerned, for some indefinite time to come most of the product of aquafarming will be too costly for local consumption and there will exist a dependence on foreign markets where prices and currency value and the modes of marketing are beyond control. Total or partial but significant reliance on foreign capital, foreign technology, foreign managers, and foreign markets can roil the emotions of any Latin American nation. Indeed, faced with this subordinate role, some countries in Latin America—Mexico is a good example—are attempting to develop aquaculture largely on their own despite delays which might be occasioned.

But this is not necessarily in the best interests of these nations. Viewed within the theme of this conference, "Science and Man in the Americas," I would rather seek for the alternative course of action which brings the benefits of aquaculture most rapidly to the largest number of people. In this light, rather than yielding to the dictates of ancient antagonisms and suspicious and too vigorous nationalism, I would rather challenge the entrepreneurs in aquaculture, whereever they may be from, this way: How can we design new enterprises so that their profitability will attract the necessary money, know-how, and management even while making of aquaculture an industry where primary operating policy is to satisfy the desires of men —"men," as I have noted, being all of us?

There is no simple answer, obviously, to this question but whatever the full answer may be, to seek it out with any hope of success requires acceptance of one basic principle, namely, that private enterprise in the Americas (indeed, everywhere in the future) cannot exist to concentrate wealth. What is allowed to be created to produce profit must in the end benefit local people more, far more, than the benefits which accrue to the original entrepreneurs who start with so much: with education, money, a sense of freedom and dignity, health, and boundless opportunity to move on.

The implications of this principle are far reaching, too much so to be fully analyzed at this time and place. Certain implications, however, are critical to our discussion. People who do not risk must nonetheless share in profits and be financed into ownership. New aquaenterprises may have to be designed so that full ownership transfers, over not too long a period, in a formal, open, politically as well as legally acceptable way, to people who are employed by, or whose lands are used by, or who live adjacent to, the aquafarm.

Financial management may thus be required to deliberately recover equity at an interest rate and capital gain acceptable not just to the original owners but to the potential owners as well. Financial management may require a policy to accelerate getting out of the project rather than staying in and benefitting from expansion. The long-range view of venture capital in aquaculture may have to be that profit per venture is limited and that

only by moving on to other sites can the capital be put to dynamic work at a satisfactory rate of return. More than this, net income may in part be required for payout to local people even before they start owning stock, as means of motivating them to accept, trust, and be inspired by management.

Management (investor) responsibility may go beyond the distribution of cash benefits which derive from corporate profits: cash as income and cash as savings in the form of stock ownership. The very existence of the aquafarm and its resources of staff, technology, and management skill may require application to the general problems of economic development among the people in the area of the enterprise, a service function which arises out of the sheer need for help among those who are not being helped by their own government, for whatever the reasons.

Lest all of these words seem an intellectual exercise and an emotional plea, I would like to conclude with a brief description of our work in Mexico which represents a working model of the foregoing principles in practice.

Coordinación Rural, A.C. (a nonprofit corporation) is a member company within Ingenieros Civiles Asociados, S.A.[1] (a profit-making corporation), a wholly Mexican-owned group of companies operating in the construction, manufacturing, and commercial sectors of the economy. Coordinación Rural—CRAC for short—receives its entire operating budget from selected companies of Ingenieros Civiles Asociados (the ICA Group); too, it is from ICA Group income that investment capital flows to acceptable rural businesses generated by CRAC. Other sources of investment capital are sought in every case but the commitment of the ICA Group, basic to thrust of CRAC, is always to participate if a project is deemed sound. There are no bottom or top limits on the size of investment opportunities being sought; no policy fixes the percentage of ICA Group equity, which may be very minor or very major, as required for implementation.

In its work, CRAC, organized at the end of 1971, seeks to attract investment and loan capital, technical transfer and management skills from the private sector to ventures in rural areas where poverty and ignorance prevail but where a combination of native intelligence, latent entrepreneurship, cultural vigor, physical resources, existing but unused technology, and infrastructure point to opportunities for commercial enterprise. CRAC searches for the site. It evaluates operational feasibility from the viewpoint of cultural, political, financial, technical, administrative, and developmental considerations. It promotes the equity and loan capital required, not only in terms of dollars but also in terms of investors who accept the policies of investment which collectively we call the principles of "popular capitalism." Finally, CRAC, which itself cannot invest legally, organizes the most appropriate corporate structure, participates in policy control, and takes responsibility for the guidance of a new enterprise into relationships with organized groups of rural people who will be the ultimate beneficiaries of the project.

Three examples of CRAC-type investments, each radically different in design but all sharing the common goal of development, may serve to clarify the relevance of CRAC to the resolution of issues impeding the growth of aquaculture.

MODEL 1 — FOMENTADORA RURAL, S.A. de C.V. (FORUSA)

FORUSA is a stock corporation with five corporate and two individual investors. Its income derives from a technical assistance contract with an organization of small-scale farmers which it helped organize and train for self-management and, from the operation of capital intensive, profit-making divisions. FORUSA pursues five courses of action simultaneously:

1. It directs, through the technical assistance contract with cooperating farmers, the modernization of traditional farming methods, leading to maximum production at maximum net return of the crops (corn, sorghum, chickpeas) normal to the area. In this case, yields have been increased 300-400 percent and net income per hectare has been tripled, not only because of higher yields but, as well, from lower interest rates on credit and improved marketing procedures.
2. It encourages farmer organization through which private bank credit can flow and training for ownership and management of businesses created by FORUSA can take place. As a result, the farmer organization now borrows directly from a private bank and is ready to initiate its own business venture, independently of FORUSA, such as a trucking division and an irrigation (from wells) division.
3. It encourages family participation in community-wide organizations through which social development is stimulated, as, for instance, the building of a potable water system, construction of a plaza, school building improvement, sewage drainage control, among others.
4. It invests in capital intensive enterprises, such as a store, and an agricultural machinery service center, out of whose profits shares are paid to the users. Net (after tax) income is in part diverted to a trust which, when funds are adequate, will buy the particular profit centers in the name of these users. By this means, income from other sources than farming, as well as employment, can be generated.
5. It invests in research and development aimed at diversifying land use to increase income per unit area, as well as to increase employment. Flower culture, multicropping, fresh vegetable production, and other activities typify this effort.

FORUSA aims to bring 10,000 acres of land under management and then withdraw from this activity as the people are organized and trained. It expects to increase family income by a factor of 10 or more. It anticipates the creation of labor demand through multicropping and business activity, even though mechanization of farming practice in inevitable. It is already refocusing the use of labor from farming to community development. It is working with the community in plans for advanced schooling. FORUSA has no doubt that as it leaves one local venture, other local investment opportunities will present themselves. Already, investment plans exist for years ahead, even while transfer-of-ownership processes are being initiated for the earliest of the businesses created.

[1]Mention of trade names or commercial organizations does not imply endorsement by the National Marine Fisheries Service, NOAA.

MODEL II — PORQUI, S.A. AND P.A.Z., S.C.

These two corporations symbolize the flexibility of CRAC concepts. For many years, Heifer Project International (of Little Rock, Ark.) successfully operated a program of introducing well-managed very small-scale animal husbandry projects into primitive communities at the family level, where opportunities for farming income were minimum. The impact of the Heifer program, first to produce food, then surplus for sale per family, and then community-wide surpluses for sale in a more organized and profitable way, has been significant in Mexico. In 1971, it became apparent that a new source of support for the program, other than U.S. philanthropy, would be necessary for program continuity and growth.

Within the history of Heifer's work in Mexico, there was an important contribution to private enterprise philosophy. At very small cost per community, people could be started toward better health, productive work, net growth in income (purchasing power) and providing a raw material base for outside investment. Therefore, it seemed justifiable to CRAC to encourage investment in any kind of profit-making enterprise whose goal it would be to use profits not only to earn income on venture capital but, more importantly, to earn the income needed to support the Heifer Project program.

In this case, it was a natural consequence of the competence of the Heifer Project staff in Mexico to invest in Porqui, S.A., a commercial piggery. At the end of less than one year* of operation, Porqui will take over the financial support of the Heifer program, which takes the name of P.A.Z., S.C., a nontaxable corporation which can receive gifts and even engage in profit-making activities so long as earnings are not paid out as dividends. As Porqui accumulates funds with which to buy out the original investors (who will have earned an attractive interest in the meanwhile), P.A.Z. becomes the owner. P.A.Z. in this way becomes self-sufficient and is provided a dynamic basis for planned growth. While local people do not become the direct beneficiaries of profit of Porqui, the benefits of profit do become focused on the rural poor over the entire nation.

MODEL III — FEED LOT

In Mexico, the primary source of milk is the very large number of small herdsmen with from five to thirty odd holsteins. Production per cow is low, a great loss in the face of a serious shortage of milk. The bull calves are generally killed within the first week after birth, since feed costs are high and for sale milk is the concern of the dairyman. This slaughter is another great loss, in the face of a serious shortage of beef, to Mexico and to potential export markets.

The feed lot planned is aimed at helping to wipe out both losses, even while diversifying the income base of the dairymen and making a good profit for the investors. Utilizing recent technical advances, a feed lot company will buy and fatten holstein bull calves for the beef market. The dairymen who supply these calves will be given veterinary services to improve the care of animals and to provide artificial insemination service to upgrade herd quality. Too, balanced feed at break-even costs will be sold to these suppliers, bringing feed costs down and production up. Credit for the suppliers to dig wells and otherwise improve their holdings and their operational efficiency will be arranged. In the end, the ownership of the feed lot will transfer to the calf suppliers. Since it is anticipated that there is room in Mexico for a chain of such feed lots, the original investors, as they leave one lot behind, can keep their money working elsewhere, over a long period of time.

In conclusion, may I note that these remarks are not intended to promote CRAC, per se. CRAC does, however, in a pragmatic way, illustrate the feasibility of combining investor interest with the all-consuming demand by the people of the Americas for social justice, for participation rather than exploitation. While I have not spoken about aquacultural ventures, CRAC is considering them and finds no difficulty of placing them within its conceptual framework. In truth, I find no field of investment excepted by the demand for broad participation in the benefits of investment in profit-making ventures. That which I said at the outset of this paper, I will say again, if somewhat differently. Aquaculture in the Americas will not be a fruitful field for foreign investors—or even to national investors—unless and until the traditional hoarding of financial benefits is cast aside.

Speaking directly to potential private investors in aquaculture, I have to say that it is not enough that the money is "yours," that "you" are taking the risk, that each man must fight for and compete for his gains. More and more in the future of the Americas, those who are able to invest privately, those who want to invest privately, and those who believe deeply in the power for economic growth inherent in private investment, must go beyond their own interests when designing projects and help lead others less fortunate toward self-sufficiency, toward pride in achievement, and toward what they dream about when they dream of the "good life."

MFR Paper 1118. From Marine Fisheries Review, *Vol. 37, No. 1, January 1975. Copies of this paper, in limited numbers, are available from D83, Technical Information Division, Environmental Science Information Center, NOAA, Washington, DC 20235.*

National Fisheries Plan Data Gathered

The National Oceanic and Atmospheric Administration, in cooperation with State Governments, is developing a plan aimed at rehabilitating U.S. marine fisheries. The Commerce Department agency said many U.S. fisheries are suffering from the effects of heavy fishing by foreign fleets as well as from depleted stocks and environmental changes. Preparation of a National Fisheries Plan was recommended recently by the President's National Advisory Committee on Oceans and Atmosphere, and NOAA's National Marine Fisheries Service was assigned the task.

NMFS Director Robert W. Schoning said that a "draft outline" of a plan has been completed by a task force and will be used to review the needs of the fisheries with various interested people in and out of government. The outline describes the present problems facing U.S. fisheries and discusses a series of major issues which are of primary concern in any effort to meet our national purposes in fisheries if they are to provide employment, food, and recreation. The outline also reviews how the issues involved can be applied in formulating a viable National Plan.

Schoning said the objective is not merely a Federal plan, since by itself the Federal Government can fill only a part of the need. The plan is intended to indicate what action is required by all concerned with our fisheries. For this reason, the full plan cannot be developed without information, opinions, and ideas from fishermen, vessel owners, processors, State fisheries managers, marine recreational fishermen, conservationists, scientific organizations, trade groups, consumers, and others.

Using the "draft outline" as a base on which to build, input from these groups has been sought at a series of meetings held from September 1974 to January 1975 in many fishing communities along our coasts. The meetings were arranged with the cooperation of Atlantic States Marine Fisheries Commission, the Gulf States Marine Fisheries Commission, the Pacific Marine Fisheries Commission, the Marine Advisory Services of the Sea Grant Colleges, and the five NMFS regional directors.

Suggestions and comments presented at these meetings will be used to develop the ideas in the draft outline into a broad National Plan which will recommend legislation and other actions. Such recommendations will assist the U.S fisheries to meet the growing demand for food and recreation, while ensuring that the valuable fisheries stocks are restored and maintained for future generations of Americans.

Van Campen Fills NMFS Tuna Development Slot

A former State Department Foreign Service Officer with wide experience in fisheries matters has been named to coordinate National Marine Fisheries Service activities with the Pacific Tuna Development Foundation. Wilvan G. Van Campen will be involved in a program designed to enable U.S. industry and the island people to benefit economically from the large tuna resources of the region, which until now have been harvested by fishermen from other countries.

Van Campen

The National Oceanic and Atmospheric Administration said Federal funds totaling $375,000 have been approved for the planned 3-year program of experimental and exploratory fishing. The Federal money will be matched by financial contributions from major sectors of the United States tuna industry and from the governments of the State of Hawaii, the island possessions of Guam and American Samoa, and the Trust Territory of the Pacific Islands.

The program will be managed by a non-profit Hawaii corporation, the Pacific Tuna Development Foundation, with directors drawn from the island governments and the tuna industry, with Van Campen representing NOAA and NMFS as Coordinator of the Central and Western Pacific Tuna Program. Eight directors of the Pacific Tuna Development Foundation were named at a late summer meeting in Honolulu: August Felando, American Tunaboat Association; Stanley Swerdloff, American Samoa; Jack Bowland, Western Fishboat Owners Association; Charles Carry, Tuna Research Foundation; John Royal, representing the fishermen's unions; Governor Carlos G. Camacho of Guam; High Commissioner Edward E. Johnston of the Trust Territory; and Andrew Gerakas of Hawaii. Appointment of a ninth member who will represent the public at large was postponed to a later date.

Van Campen comes to the Commerce Department agency from the Department of State where he has been a Fisheries Specialist for the past seven years. He is familiar with the Pacific area, having served as Executive Secretary of the International North Pacific Fisheries Commission, Fisheries Attache at the U.S. Embassy in Tokyo, and with the NMFS at its Honolulu laboratory. Van Campen will be located at NMFS Southwest Fisheries Center in La Jolla, Calif., and report to the Southwest Regional Office of NMFS.

Evans Named to NMFS Environmental Post

The Commerce Department's National Oceanic and Atmospheric Administration has announced that Dale R. Evans has joined the Washington staff of the National Marine Fisheries Service as Chief of the Environmental Assessment Division, Office of Resource management.

Evans

Evans joins the staff from the NMFS in Alaska where he was the Regional Coordinator in the Environmental Assessment Division. Prior to that Evans was actively involved in the Alaskan River Basin Studies and served as a Fishery Management Biol-

ogist at King Salmon and Anchorage, Alaska.

The division Mr. Evans will head has the responsibility for determining the effects of Federal water projects on fisheries resources, particularly activities of the U.S. Army's Corps of Engineers, the Bureau of Reclamation in the Department of the Interior, and certain functions of the Department of Agriculture.

Mr. Evans has a B.S. in Fisheries and Game Management from Oregon State University and has done graduate work in Natural Resources Economics at the George Washington University and the University of Alaska.

NOAA Selects Snyder To Be Naval Deputy

Appointment of Rear Admiral J. Edward Snyder, Jr., as his Naval Deputy has been announced by Robert M. White, Administrator of the National Oceanic and Atmospheric Administration.

Snyder will remain in his present position as Oceanographer of the Navy, assuming the position of Naval Deputy to the NOAA Administrator as additional duty. He succeeds William W. Behrens, Jr., who recently retired.

As Naval Deputy to the Administrator of the Commerce Department agency, Snyder works to foster closer accord between the Navy and NOAA in the sciences, particularly oceanography. Navy assignment to the position helps to ensure close coordination of the national oceanographic program. Snyder has served as Oceanographer of the Navy since June, 1972.

From 1963 to 1967, he served as Special Assistant to the Assistant Secretary of the Navy for Research and Development and as executive assistant to the Chairman of the Federal Interagency Committee on Oceanography. For his performance as special assistant, he was awarded the Legion of Merit for exceptionally meritorious service in the Navy and National Oceanographic Programs from 1936 to 1967. In addition, in 1967, Snyder was awarded the Navy League's Rear Admiral W.S. Parsons Award for scientific and technical progress in Navy oceanography and for his personal contributions to the National Oceanographic Programs.

He was born 23 October 1924, in Grand Forks, N.D. He is a graduate of the U.S. Naval Academy and the U.S. Naval War College, and holds a Master of Science Degree in Nuclear Physics from Massachusetts Institute of Technology. Snyder was first commissioned in 1944, saw action in the Pacific on the battleship *USS Pennsylvania* during World War II, and then served in cruisers until he entered the nuclear field in 1948. In 1949 he was a staff member of the Los Alamos Scientific Laboratory engaged in atomic weapon research and development.

In July 1958, Snyder completed a year and a half as commanding officer of the radar picket destroyer escort *USS Calcaterra*. He later spent two years in command of the destroyer *USS Brownson*.

Snyder achieved his second Legion of Merit award for his "exceptionally meritorious conduct" as commanding officer of the battleship *USS New Jersey* in action off the coast of Vietnam in 1968-69. In August 1971 he went to Norfolk, Virginia as Commander of the U.S. Atlantic Fleet Training Command. It was for his performance of duty while in the training command assignment that Snyder was awarded his third Legion of Merit. Snyder is married and has two children. He is a member of Sigma Xi, the honorary society for scientific research.

STATE BODY STUDIES FISHERIES MANAGEMENT

A comprehensive study to assist State legislators in formulating effective legislation for managing fisheries is being conducted by the Council of State Governments under a contract signed recently with the National Oceanic and Atmospheric Administration. High on the list of issues to be studied, according to the Commerce Department agency, are the present and potential roles played by State governments in managing fisheries along the seacoasts and in the Great Lakes. The Council's Committee on Suggested State Legislation produces an annual volume of suggested State laws on many subjects. In addition to a "model" act on fisheries management, a specially assigned task force under terms of the new contract will prepare a detailed report covering fisheries management at the State level. The recommendations and report will be presented to State representatives at a national conference of the Council this spring.

The task force will be composed of State officials, including State legislators and administrative officers having major responsibilities in State fisheries management programs. An organizational meeting on the project was held in late July 1974 in Denver, Colo. Attending the meeting were: Thomas E. Kruse, Director, Fish Commission of Oregon; Frank Grice, Director, Division of Marine Resources, Massachusetts; Ed J. Huizer, Deputy Commissioner, Alaska Department of Fish and Game; State Senator Sanford Steckler of Mississippi; and State Representative Thomas Anderson of Michigan. Robert Hutton, Associate Director for Resource Management; Richard Schaefer, Chief, Office of State-Federal Relationships; and Stephen Powell of the Office of General Counsel represented NOAA and its National Marine Fisheries Service, while James Ridenour and Robert Mathews represented the Council of State Governments, headquartered in Lexington, Ky. A meeting of the full task force was held later on the west coast, and the group meets periodically throughout the 1-year study period as needed. Staff work is being performed by the State Services Office of the Council of State Governments, with assistance provided by NMFS.

To obtain independent perspectives on the framework of legislation that may be proposed, considerable travel will be undertaken by task force members. They will contact appropriate fisheries agency directors, industry leaders, recreational fishermen, and others knowledgeable on the needs of U.S. fisheries.

The Council of State Governments is a research and service organization, jointly supported by all States, which supplies extensive information intended to benefit the States within the Federal system, assists in State-Federal liaison, and provides staff services for affiliated organizations.

United States and Poland Establish a Plankton Sorting Center on the Baltic

The United States and Poland have agreed to establish the world's only known center specifically designed for advanced plankton sorting techniques. (Plankton is the microscopic animal and plant life found drifting or floating in the ocean or fresh water. It makes up the primary food source for many fish.)

The Center will be located at Szczecin on the northeast coast of Poland and will be a joint venture between the National Oceanic and Atmospheric Administration and Poland's Sea Fisheries Institute. A building has already been constructed on the campus of the College of Agriculture and Fisheries at Szczecin to house the Center, and includes a lecture hall, three scientific laboratories, and a large sorting room capable of handling up to 3,000 plankton samples a year.

The Commerce Department agency said that during the coming 6 months a plankton sorting and taxonomy training program will be started involving an exchange of scientists between the two countries. Stefhan Grimm and Idzi Drzycimski visited the Northeast Fisheries Center facilities at Woods Hole, Mass., and Narrangansett, R. I., for training in plankton sorting and taxonomy for three weeks in September. Both facilities are operated by NOAA's National Marine Fisheries Service.

In October Elbert Ahlstrom of the NMFS Fisheries Center at La Jolla, Calif., visited the Polish facility for several weeks to train Polish fisheries scientists in larval toxonomy.

The Polish Center will provide sorting services for plankton samples collected in joint surveys conducted by the International Commission for the Northwest Atlantic Fisheries (ICNAF) of which both Poland and the United States are members. The work will be especially helpful in ICNAF assessment studies now taking place in the northwest Atlantic.

Plankton sorting is a time consuming and expensive operation when done by hand, as is now the general practice, but in addition to routine sorting operations, the staff at the new Center will test and employ automatic systems including fluid separation devices utilizing the specific gravity of different sorts of plankton.

The new Center is expected to cost about $350,000 with $200,000 from the Polish Government and the remainder from U.S. counterpart funds allocated to NOAA. Counterpart funds are those held in foreign countries as a result of trade for use only in that country by the United States.

Secretary Dent Denies Seal Skin Import Permit

Secretary of Commerce Frederick B. Dent announced in September that he would not waive the prohibition against importation of seal skins from South Africa and South West Africa to the United States. Under the terms of the Marine Mammal Protection Act of 1972, importation is unlawful if the Secretary deems the harvest to be inhumane. Secretary Dent dispatched a team of independent veterinary consultants to view the harvest in August, and their report indicated that it was not humanely conducted.

The decision effectively denies an application by the Fouke Company, Greenville, S.C., for the right to import such skins from the South African and South West African harvest.

The Secretary issued the following statement:

"In November of 1973, the Fouke Company sought a waiver of a moratorium on fur seal importation provided under the terms of the Marine Mammal Protection Act of 1972, to import South African and South West African fur seal skins in unspecified numbers for the ensuing ten years.

"In December of 1973, the Company sought a waiver to allow importation of 5,600 skins left over from the 1973 harvest.

"The waiver of the moratorium, if granted, would precede an application by Fouke for permits to import the skins.

"The Marine Mammal Protection Act states that importation is unlawful if the animals are 'taken in a manner deemed inhumane by the Secretary.'

"Accordingly, I sought the expert opinions of two distinguished veterinary consultants, Dr. Wallace M. Wass, head of the Department of Veterinary Clinical Sciences at Iowa State University, and Dr. Leslie E. McDonald, Assistant Dean, Department of Physiology and Pharmacology, College of Veterinary Medicine, University of Georgia, on the way in which the South African harvest is conducted.

"Accompanied by Joseph Blum, marine mammal program coordinator in the National Oceanic and Atmospheric Administration's National Marine Fisheries Service, they spent a part of August in South Africa and South West Africa observing the practices involved in the taking of the seals.

"It was established that the killing methods were inadequately carried out in many instances, and that the procedures failed to meet the standards required by our Marine Mammal Protection Act.

"Many workers were untrained or inadequately trained.

"In the light of my responsibilities, under the law, I must refuse the present application by the Fouke Company to allow importation of the skins, and I am so doing."

NOAA Contract Seeks Fish Name Standards

A contract authorizing studies that will eventually help consumers of fish and fishery products identify various species and products has been awarded to the Brand Group, Inc., Chicago, by the National Oceanic and Atmospheric Administration. The Commerce Department agency said the $63,000 contract calls for the Chicago concern to analyze, plan, and recommend methods of developing an effective identification system to clarify and standardize market names of certain fish species and products.

NOAA's National Marine Fisheries Service will work with the contractor in reviewing and evaluating the current criteria and principles now used in establishing food product names, and seek to identify inconsistent and obsolete names that may now be in use. A new set of principles particularly applicable to fish and fisheries products is also being sought.

The need for such a program be-

came apparent a few months ago when more than 500 responses were received to a Fisheries Service request for suggestions and opinions as to the desirability of efforts to standardize the names of certain fish and fisheries products. The announcement pointed out that thousands of species are known throughout the world by scientifically accurate names, but differing and sometimes confusing common names used in labeling products from some species cause problems in marketing and market development, and could disrupt attempts to write uniform labeling regulations. The Fisheries Service also said there is increasing interest in using fish and shellfish that, to date, have not been marketed generally, and for which no common names exist that are familiar to consumers. A spokesman said that new food processing techniques such as the use of minced fish blocks present opportunities to develop new products that have no recognized market names.

After the report and recommendations are made by the contractor in April 1975, NMFS will consult with appropriate organizations in the public and private sectors relative to plans and procedures. Considerable time will be required before the program can be completed. Actions will be coordinated with interested parties such as the Food and Drug Administration, the American Fisheries Society, consumer groups, and the fishing industry.

Foreign Fishery Developments

Japan Tells 1972-73 Fishery Product Trade

EXPORTS

In 1973 the value of Japan's fishery exports were 21 percent higher than during the previous year: $636 million versus $527 million exported in 1972.

Table 1.—The value of Japan's fishery exports, by country and share of market, 1972-73.

Country	1973 Value[1]	1973 Share[2]	1972 Value[1]	1972 Share[2]
United States	226	35.5	194	36.8
Great Britain	39	6.1	41	7.8
West Germany	32	5.1	25	4.7
Canada	27	4.3	19	3.7
Switzerland	23	3.6	15	2.8
Taiwan	22	3.4	10	1.8
Australia	20	3.1	15	2.9
Philippines	19	3.1	17	3.2
Hong Kong	17	2.7	13	2.4
Puerto Rico (U.S.)	16	2.6	20	3.7
Other	195	30.5	158	30.2
Total exports	636	100.0	527	100.0

[1]Values in US$1 million.
[2]Shares in percent.
Source: Japanese Customs Returns.
Exchange Rates: 1973: 273 Yen = US$1.00
1972: 308 Yen = US$1.00

Table 2.—The value of Japan's fishery exports, by commodity and share of the market, 1972-73.

Commodity	1973 Value[1]	1973 Share[2]	1972 Value[1]	1972 Share[2]
Mackerel, canned	96	15.1	76	14.4
Tuna, Canned	90	14.1	88	16.7
Tuna, Frozen	79	12.4	58	10.9
Pearls	65	10.3	46	8.7
Salmon, canned	38	6.0	56	10.6
Squid, frozen	17	2.7	11	2.1
Shrimp, frozen	13	2.0	12	2.3
Saury, frozen	12	1.9	12	2.3
Other fish, live	12	1.9	3	.6
Fish oil	10	1.6	5	1.0
Other	204	32.0	160	30.4
Total exports	636	100.0	527	100.0

[1]Values in US$1 million.
[2]Shares in percent.
Source: Japanese Customs Returns.
Exchange Rates: 1973: 273 yen = US$1.00
1972: 308 yen = US $1.00

The United States was Japan's largest market in both years, accounting for 37 percent and 36 percent of Japan's total fishery exports for 1972 and 1973 respectively. Table 1 provides statistical data on Japan's fishery exports by country for 1972-73.

Canned mackerel and tuna, frozen tuna, and pearls were the most valuable of Japan's fishery exports in 1973. Because of fishing restrictions which affected Japan's salmon catch, exports of canned salmon declined in 1973. Table 2 provides data on Japan's fishery exports by commodity for the period 1972-73.

The Philippines purchased 18 percent of Japan's canned mackerel exports, followed by the United States (11 percent) and Singapore (10 percent). The United States was Japan's largest importer of canned tuna (31 percent) followed by Canada (20 percent) and Great Britain (12 percent). Almost all of Japan's frozen tuna (88 percent) went to the United States and Puerto Rico. Great Britain (55 percent) and Australia (26 percent) were leading buyers of Japanese canned salmon in 1973. Table 3 provides data on Japan's exports of fishery commodities by country for 1973.

Table 3. — Value of Japan's fishery exports, by commodity, country, and share of the market, 1973.

Commodity and Country	Value[1]	Share[2]	Commodity and Country	Value[1]	Share[2]
Canned Mackerel			Frozen Shrimp		
Philippines	18	18.3	Guiana	6	46.9
United States	11	11.0	United States	3	24.9
Singapore	10	10.4	Surinam	2	17.5
Ghana	6	6.8	Trinidad & Tobago	1	7.4
Papua-New Guinea	6	6.3	Nigeria	1	2.1
Other	45	47.2	Other	—	—
Total	96	100.0	Total	13	100.0
Canned Tuna			Frozen Saury		
United States	31	34.7	American Samoa	3	20.9
Canada	20	22.4	Madagascar	1	9.8
Great Britain	12	12.9	New Hebrides	1	7.1
Switzerland	7	7.9	South Korea	1	7.0
West Germany	7	7.7	Canary Islands	1	6.9
Other	13	14.4	Other	5	48.3
Total	90	100.0	Total	12	100.0
Frozen Tuna			Fish Meal		
United States	54	68.0	Taiwan	7	82.9
Puerto Rico (U.S.)	16	20.4	West Germany	1	10.6
Papua-New Guinza	2	3.1	Australia	—	2.7
Spain	2	2.8	South Africa	—	1.9
Italy	1	1.5	Hong Kong	—	.8
Other	4	4.2	Other	—	—
Total	79	100.0	Total	8	100.0
Canned Salmon			Canned Oyster		
Great Britain	21	55.3	United States	5	60.8
Australia	10	26.3	Canada	2	21.7
Netherlands	3	7.9	Austria	—	7.4
United States	2	5.3	South Africa	—	3.2
New Zealand	1	2.6	New Zealand	—	1.6
Other	1	2.6	Other	—	—
Total	38	100.0	Total	7	100.0

[1]Values in US$1 million.
[2]Shares in percent.

Source: Japanese Customs Returns.
Exchange Rate: 273 Yen = US$1.00.

IMPORTS

South Korea exported $173 million worth of fishery products to Japan in 1973, making this nation Japan's most important supplier of fishery products. Taiwan was Japan's second largest supplier followed, surprisingly, by the United States which exported $89 million worth of fishery products to Japan; this amount accounts for 8.1 percent of Japan's total imports for 1973. Table 4 provides data on Japan's imports, by country, for the period 1972-73.

Frozen shrimp accounted for nearly 40 percent of Japan's total imports. In 1973 the Japanese purchased an estimated $433 million worth of shrimp, again breaking all records. Herring roe imports totaled $77 million making this product Japan's second most important import. Tuna, salmon roe, octopus, salmon, eel, fish meal, squid, and crab were also imported in significant quantities in 1972-73. Table 5 provides data on Japan's imports by major commodities during 1972-73.

Indonesia, India, Mexico, Thailand, and Australia were Japan's principal suppliers of shrimp in 1973. The People's Republic of China—which also sent sizeable shipments of shrimp to Japan during the year—was Japan's most important supplier of herring roe followed by Canada and South Korea. Most of Japan's fresh and frozen tuna came from South Korea and Taiwan. The United States was Japan's principal supplier of salmon roe and frozen salmon. Practically all of Japan's imports of live eels came from Taiwan during the year with small amounts being shipped from other nations including the United States. Table 6 provides data on Japan's imports of fishery products by commodity and country for 1973.

Table 4.—The value of Japan's fishery imports, by country and share of market, 1972-73.

	1973		1972	
Country	Value[1]	Share[2]	Value[1]	Share[2]
South Korea	173	15.7	80	12.9
Taiwan	93	8.4	56	9.1
United States	89	8.1	25	4.0
Indonesia	81	7.4	49	7.9
China, Mainland	76	6.9	50	8.0
India	65	5.9	40	6.5
Canada	64	5.8	24	3.8
Thailand	52	4.7	33	5.4
Mexico	45	4.1	23	3.7
Australia	40	3.6	28	4.5
Other	321	29.4	210	34.2
Total imports	1,099	100.0	618	100.0

[1]Values in US$1 million.
[2]Shares in percent.
Source: Japanese Customs Returns.
Exchange Rates: 1973: 273 Yen = US$1.00
1972: 308 Yen = US$1.00

Table 5.—The value of Japan's fishery imports, by commodity and share of the market, 1972-73.

	1973		1972	
Commodity	Value[1]	Share[2]	Value[1]	Share[2]
Shrimp, frozen	433	39.4	292	47.2
Herring roe	77	7.0	33	5.3
Tuna, fresh-frozen	52	4.7	34	5.5
Salmon roe	44	4.1	25	4.0
Octopus, frozen	42	3.8	32	5.2
Salmon, frozen	41	3.8	3	.5
Eel, live	39	3.5	n.a.	n.a.
Fish meal	32	2.9	11	1.7
Squid, frozen	30	2.7	21	3.4
Crab, frozen	21	1.9	3	.5
Other	288	26.2	164	26.7
Total imports	1,099	100.0	618	100.0

[1]Values in US$1 million.
[2]Shares in percent.
Source: Japanese Customs Returns.
Exchange Rates: 1973: 273 Yen = US$1.00
1972: 308 Yen = US$1.00

Table 6. — Value of Japan's fishery imports, by commodity, country, and share of the market, 1973.

Commodity and Country	Value[1]	Share[2]	Commodity and Country	Value[1]	Share[2]
Frozen Shrimp			Frozen Salmon		
Indonesia	74	17.1	United States	29	70.8
India	64	14.8	Canada	11	27.4
Mexico	43	10.0	Soviet Union	—	.6
Thailand	35	8.1	North Korea	—	.5
Australia	27	6.2	South Korea	—	.4
China, Mainland	23	5.4	China, Mainland	—	.1
Other	167	38.4	Other	—	—
Total	433	100.0	Total	41	100.0
Herring Roe			Live Eels		
China, Mainland	34	43.7	Taiwan	38	98.1
Canada	26	33.6	China, Mainland	—	.5
South Korea	11	13.9	New Zealand	—	.5
United States	5	6.5	Indonesia	—	.4
Hong Kong	1	1.6	South Korea	—	.2
North Korea	—	.6	United States	—	.1
Other	—	—	Other	—	—
Total	77	100.0	Total	39	100.0
Fresh & Frozen Tuna			Fish Meal		
South Korea	22	42.3	Angola	12	36.1
Taiwan	18	34.6	Southwest Africa	6	17.4
Panama	5	9.5	Peru	5	16.0
United States	2	3.9	Thailand	2	7.3
Canada	1	1.2	Soviet Union	2	7.1
Maldive Islands	1	1.0	South Africa	2	6.8
Other	4	7.5	Other	3	9.3
Total	52	100.0	Total	32	100.0
Salmon Roe			Frozen Crab		
United States	24	55.5	United States	14	67.1
Canada	20	44.3	South Korea	6	29.7
Denmark	—	.1	China, Mainland	—	1.3
Sweden	—	.1	North Korea	—	.9
West Germany	—	—	Canada	—	.4
Other	—	—	Taiwan	—	.3
Total	44	100.0	Other	—	—
			Total	21	100.0

[1]Values in US$1 million.
[2]Shares in percent.
Source: Japanese Customs Returns
Exchange Rate: 273 Yen = US$1.00
Note: Totals do not necessarily agree with data due to rounding. Each listed country provided fractional exports if no figure is shown.

Peru, U.S. Company Enter Joint Venture

Star-Kist Overseas, Inc. and the Peruvian Government Company Empresa Publica de Servicios Pesquera (EPSEP), responsible for developing fish for human consumption, announced the formation of a new joint fishing venture called Cia Pesquera Estrella de Peru SA (COPES) late last summer.

Final documents for the formation of COPES were signed in Washington, D.C. by Col. Luis Villacorta Boydo, Executive Director of EPSEP and John J. Real, Vice-president of Star-Kist. Present at the signing ceremony was Peru's Minister of Fisheries General Javier Tantalean Vanini.

COPES will be a processing company and is expected to can fish products for local consumption and for export. The Peruvian entity EPSEP will own 51 percent of the company's stock and Star-Kist will control the remaining 49 percent of the stock. A total investment of $4.5 million is anticipated.

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